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SUMMARY TECHNICAL REPORT
OF THE
NATIONAL DEFENSE RESEARCH COMMITTEE

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SUMMARY TECHNICAL REP... OF DIVISION 6, NDRC

VOLUME 11

A MANUAL OF CALIBRATION MEASUREMENTS OF SONAR EQUIPMENT

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

VANNEVAR BUSH, DIRECTOR

NATIONAL DEFENSE RESEARCH COMMITTEE

JAMES B. CONANT, CHAIRMAN

DIVISION 6

JOHN T. TATE, CHIEF

WASHINGTON, D. C., 1946

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NOTES ON THE ORGANIZATION OF NDRC

The duties of the National Defense Research Committee were (1) to recommend to the Director of OSRD suitable projects and research programs on the instrumentalities of warfare, together with contract facilities for carrying out these projects and programs, and (2) to administer the technical and scientific work of the contracts. More specifically, NDRC functioned by initiating research projects on requests from the Army or the Navy, or on requests from an allied government transmitted through the Liaison Office of OSRD, or on its own considered initiative as a result of the experience of its members. Proposals prepared by the Division, Panel, or Committee for research contracts for performance of the work involved in such projects were first reviewed by NDRC, and if approved, recommended to the Director of OSRD. Upon approval of a proposal by the Director, a contract permitting maximum flexibility of scientific effort was arranged. The business aspects of the contract, including such matters as materials, clearances, vouchers, patents, priorities, legal matters, and administration of patent matters were handled by the Executive Secretary of OSRD.

Originally NDRC administered its work through five divisions, each headed by one of the NDRC members. These were:

Division A—Armor and Ordnance
Division B—Bombs, Fuels, Gases, & Chemical Problems
Division C—Communication and Transportation
Division D—Detection, Controls, and Instruments
Division E—Patents and Inventions

In a reorganization in the fall of 1942, twenty-three administrative divisions, panels, or committees were created, each with a chief selected on the basis of his outstanding work in the particular field. The NDRC members then became a reviewing and advisory group to the Director of OSRD. The final organization was as follows:

Division 1—Ballistic Research
Division 2—Effects of Impact and Explosion
Division 3—Rocket Ordnance
Division 4—Ordnance Accessories
Division 5—New Missiles
Division 6—Sub-Surface Warfare
Division 7—Fire Control
Division 8—Explosives
Division 9—Chemistry
Division 10—Absorbents and Aerosols
Division 11—Chemical Engineering
Division 12—Transportation
Division 13—Electrical Communication
Division 14—Radar
Division 15—Radio Coordination
Division 16—Optics and Camouflage
Division 17—Physics
Division 18—War Metallurgy
Division 19—Miscellaneous
Applied Mathematics Panel
Applied Psychology Panel
Committee on Propagation
Tropical Deterioration Administrative Committee

NDRC FOREWORD

As events of the years preceding 1940 revealed more and more clearly the seriousness of the world situation, many scientists in this country came to realize the need of organizing scientific research for service in a national emergency. Recommendations which they made to the White House were given careful and sympathetic attention, and as a result the National Defense Research Committee [NDRC] was formed by Executive Order of the President in the summer of 1940. The members of NDRC, appointed by the President, were instructed to supplement the work of the Army and the Navy in the development of the instrumentalities of war. A year later, upon the establishment of the Office of Scientific Research and Development [OSRD], NDRC became one of its units.

The Summary Technical Report of NDRC is a conscientious effort on the part of NDRC to summarize and evaluate its work and to present it in a useful and permanent form. It comprises some seventy volumes broken into groups corresponding to the NDRC Divisions, Panels, and Committees.

The Summary Technical Report of each Division, Panel, or Committee is an integral survey of the work of that group. The first volume of each group's report contains a summary of the report, stating the problems presented and the philosophy of attacking them, and summarizing the results of the research, development, and training activities undertaken. Some volumes may be "state of the art" treatises covering subjects to which various research groups have contributed information. Others may contain descriptions of devices developed in the laboratories. A master index of all these divisional, panel, and committee reports which together constitute the Summary Technical Report of NDRC is contained in a separate volume, which also includes the index of a microfilm record of pertinent technical laboratory reports and reference material.

Some of the NDRC-sponsored researches which had been declassified by the end of 1945 were of sufficient popular interest that it was found desirable to report them in the form of monographs, such as the series on radar by Division 14 and the monograph on sampling inspection by the Applied Mathematics Panel. Since the material treated in them is not duplicated in the Summary Technical Report of NDRC, the monographs are an important part of the story of these aspects of NDRC research.

In contrast to the information on radar, which is of widespread interest and much of which is released to the public, the research on subsurface warfare is largely classified and is of general interest to a more restricted group. As a consequence, the report of Division 6 is found almost entirely in its Summary Technical Report, which runs to over twenty volumes. The extent of the work of a Division cannot therefore be judged solely by the number of volumes devoted to it in the Summary Technical Report of NDRC: account must be taken of the monographs and available reports published elsewhere.

Any great cooperative endeavor must stand or fall with the will and integrity of the men engaged in it. This fact held true for NDRC from its inception, and for Division 6 under the leadership of Dr. John T. Tate. To Dr. Tate and the men who worked with him—some as members of Division 6, some as representatives of the Division's contractors—belongs the sincere gratitude of the Nation for a difficult and often dangerous job well done. Their efforts contributed significantly to the outcome of our naval operations during the war and richly deserved the warm response they received from the Navy. In addition, their contributions to the knowledge of the ocean and to the art of oceanographic research will assuredly speed peacetime investigations in this field and bring rich benefits to all mankind.

The Summary Technical Report of Division 6, prepared under the direction of the Division Chief and authorized by him for publication, not only presents the methods and results of widely varied research and development programs but is essentially a record of the unstinted loyal cooperation of able men linked in a common effort to contribute to the defense of their Nation. To them all we extend our deep appreciation.

Vannevar Bush, Director
Office of Scientific Research and Development

J. B. Conant, Chairman
National Defense Research Committee

FOREWORD

THIS REPORT, supplementing Volume 10 on calibration methods, presents a compilation of data relative to a wide variety of projectors and hydrophones. Certain of these units developed were for use as standards while others were developed as parts of gear intended for service use. The agency developing the instrument or devices is in each case indicated. The acoustical and electrical data included are based on tests made at the Mountain Lakes, New Jersey and Orlando, Florida test stations of the Underwater Sound Reference Laboratories [USRL] operating under Contract OEMsr-1130 with Columbia University. This report has been prepared by that organization.

It may be stated that a somewhat less comprehensive compilation was undertaken several years ago in the form of the *Dictionary of Underwater Acoustical Devices* issued by USRL. The usefulness and wide acceptance of the dictionary seems to justify the more comprehensive assembling of the material

In carrying on the work described in this report the Division and its contractor have had the cordial support and counsel of the Office of the Coordinator of Research and Development. In addition constant and most helpful contact has been maintained with the Navy liaison officers designated for the various projects. On page 352 are listed the principal Navy projects under which this particular work was performed.

The Division also wishes to express its appreciation of the cooperation afforded by a number of industrial organizations operating under Navy contracts. These have furnished models for test and members of their staffs have given time freely to the Hydrophone Advisory Committee (see page 353).

JOHN T. TATE
Chief, Division 6

PREFACE

THIS VOLUME summarizes and presents the calibrations made by the Underwater Sound Reference Laboratories on various sonar equipment developed by the NDRC, as well as by the Navy and its contractors. It includes not only those data originally in the USRL *Dictionary of Underwater Acoustical Devices*, but also additional information collected during 1944 and 1945.

As it is intended that this volume serve primarily as a reference for those interested in the basic performance figures of sonar gear, the information has been grouped arbitrarily into seven chapters.

The scientific staffs at the Mountain Lakes and Orlando stations, together with those of other Division 6 and naval laboratories, have collaborated in collecting data included in this volume and preparing it in suitable form for publication. This group includes: Edwin L. Carstensen, E. Dietze, W. Richard Elliott, Leslie L. Foldy, Frank H. Graham, Earle C. Gregg, Jr., Erhard Hartmann, Norma Hartmann, F. William Hoffman, Paul F. Joly, Joseph B. Keller, Martin J. Klein, L. Pauline Leighton, Lucille Northrop, Henry Primakoff, Edward S. Rogers, Robert S. Shankland, Erwin F. Shrader, D. Bernard Simmons, Richard J. Tillman.

ROBERT S. SHANKLAND
Editor

CONTENTS

Chapter 1

STANDARDS USED BY THE UNDERWATER SOUND REFERENCE LABORATORIES

1.1 INTRODUCTION

As pointed out previously[a] most of the calibration tests made by the Underwater Sound Reference Laboratories [USRL] have been the comparison type, in which measurements relative to a standard are taken. A standard can be defined as a device for which an absolute calibration is available and which is used as a basis of comparison in testing other instruments.

Before the reciprocity method was established and applied by the USRL as a means for obtaining absolute calibrations, a distinction was made between primary standards, which were calibrated by absolute means, and secondary standards, which were calibrated by comparison with the primary standards and then in turn used as standards in comparison tests. Often the secondary standards had certain practical advantages as they were more rugged, had a higher output level, could handle a larger input, etc.

The 1A pressure gradient hydrophone (see Section 1.4.10) is one of the primary standards that was used by the USRL. Its response in air and water is predictable from its design constants, that is, the area and mass of the magnet and moving coil, the flux density in the air gaps, and the length of the conductor in the coil.[a] The predicted performance was checked by means of response measurements in air, and the calibration in water was then worked out from that in air.[a]

Another primary standard used by the USRL is the CMF hydrophone (see Section 1.4.18), which can be calibrated in absolute terms on a quasistatic[a] basis.

A third example is the low-frequency pressure tank system, which is capable of being calibrated on an absolute basis independent of auxiliary hydrophone standards.[b]

Comparison of Projector Standards Manufactured by BTL on NDRC Contract for USRL

Code No.	Type of construction	Frequency range (kc)	Maximum permissible input (w)	Directivity index (db)
5A	ADP	20–150	0.1	−13.0 (70 kc)
2B	Y-cut Rochelle salt	7.5–28	7	−9.0 (23 kc)
3B	Y-cut Rochelle salt	28–100	Decreases with frequency from 5 to 0.5	−8.0 (30 kc)
4B	Moving coil	0.008–0.5	125	Nondirective
6B	Y-cut Rochelle salt	10–80	0.1	−16.3 (70 kc)
1K	Moving coil	0.1–10	20 above 400 c	Nondirective
MH	X-cut quartz	100–2,200	3	−19.5 (150 kc)

With the reciprocity calibration method all instruments, provided at least one of them is reversible, can be calibrated independently so that the difference between primary and secondary standards largely disappears. Instruments can then be selected as standards merely on the basis of the suitability of their characteristics.[a]

One of the most important requirements for a standard[a] is dependability, that is, a standard should give the same performance day in and day out under various conditions of use so that,

[a] See STR Division 6, Volume 10, Chapter 5.
[b] See STR Division 6, Volume 10, Chapter 3.

once its calibration has been determined, it can be relied upon for an extensive period of time and under a wide range of testing conditions. This requirement is more easily met in hydrophones than in projectors, the latter being subject to heating, internal temperature stresses, etc., produced by the power dissipated in the projector. The problem of dependability is mainly one of design, including the material of which the instrument is made. The X-cut Rochelle salt crystal, because of its temperature dependence, for instance, should in general be avoided for standards. Instead, 45° Y-cut crystals have been used. A disadvantage of the Y-cut crystal is its high electric impedance, which demands the use of a high input impedance preamplifier in order to obtain an appreciable fraction of the generated voltage. On the other hand, the Y-cut crystal has no hysteresis and its constants are practically independent of temperature and loading constraint. More recently ADP (ammonium dihydrogen phosphate, $NH_4H_2PO_4$) crystals have come into use and are now replacing the Y-cut Rochelle salt crystal. The ADP is cut along the Z axis. Its acoustical and electrical characteristics are similar to those of Y-cut Rochelle salt, but its mechanical characteristics are superior. It is stable in air up to 93 per cent humidity and its melting temperature point is at 190 C, although at 125 C loss of ammonia results.

1.3 PROJECTOR STANDARDS

The majority of the standards used by the USRL have been designed by the Bell Telephone Laboratories [BTL] on NDRC contract expressly for calibration purposes, in accordance with requirements for frequency range, output level, directivity, etc., furnished by the USRL. The following projector standards have been produced on this basis.

For the low-frequency range, the 4B and 1K projector standards are used by the USRL. These are both electrodynamic units.[a] This type unit seems to be particularly well suited for the generation of low frequencies. The British hydrosounder and a low-frequency source designed by the Naval Ordnance Laboratory are also of this type.

The efficiency of the 4B and 1K units is of the order of —25 to —30 db vs the ideal, whereas crystal projectors have been designed, but not for the low frequencies, with only a few decibels loss. The low efficiency of the dynamic unit is due to the large dissipation in the copper and iron. Not only is the efficiency low but the amount of power which can be applied to the units is limited by overheating. At low frequencies another factor limits the output, namely, the maximum amplitude of motion that the diaphragm can produce. Also the static pressure must at all times be equal on both sides of the diaphragm. How this pressure equalization is accomplished is covered in the description of the two units. When the necessary precautions are taken,[4, 38] it is possible to use these units at depths up to 50 ft, which is as great as any normally required in USRL calibrating work.

At the higher frequencies it is possible to use crystal projectors. These are efficient and have reasonably uniform response. The useful frequency range of any one projector, however, is limited by the size of the projector. As the frequency is increased, a unit of a given size becomes more and more directional until finally the beam becomes so sharp that it no longer provides a uniform sound field for testing. When the projector beam is too sharp, any small change in alignment of the testing system causes large changes in sound level at the test point. For this reason, among others, the 6B is used only to 30 kc, and the 5A projector, which is smaller and hence less directional, is used above 30 kc. Similar considerations are applicable to the MH transducers, which are used in the high-frequency system. The crystal unit used from 100 to 300 kc has a diameter of 3 cm, whereas the one used from 300 kc to 2.2 mc has a 1-cm diameter.

The 2B and 3B projectors consist of an array of 45° Y-cut crystal blocks of different sizes, each mechanically resonated at its own natural frequency by means of a half-wavelength resonator. This leads to a highly efficient design.

[a] See STR Division 6, Volume 10, Chapter 2.

These units, however, have not proven too satisfactory for the close-up, precision testing that comprises most of the work done by the USRL. This is because of the phase difference between the sound from the different crystals and the shift in the origin of the sound field position with the change in the contribution from the different crystals. For these reasons the sound intensity does not obey the inverse square law distance relation too well until the testing distance becomes so great (at least 10 m) that the whole unit approximates a point source. Therefore, these projectors have been used more by other groups in the underwater sound field who test at greater distances than the USRL.

In addition to the above, a number of transducers made by the Brush Development Company of Cleveland, Ohio, have been used as sound sources by the USRL, particularly the C13 and the AX-70, which have good directivity characteristics in the supersonic range but which, being made of X-cut Rochelle salt crystals, are subject to change with temperature. For a projector with this characteristic, it is not sufficient that the water temperature be constant, because the crystal temperature will increase whenever power is applied to it. The performance of these units may be fairly well controlled by supplying them from a high-impedance source. The efficiency of such a system is low, since a large fraction of the supplied power is dissipated in the source. It is realized that a constant current circuit would minimize these troubles to a considerable degree. The Brush Development Company has recently produced the AX-124 transducer (see Section 1.4.2). This unit, which is essentially the C13 with ADP crystals and is free from temperature effects, would be considerably more satisfactory for use as a sound source.

1.3 HYDROPHONE STANDARDS

The general requirements for the selection of a hydrophone for use as a standard have been outlined previously.[d] However, the selection of a standard for a particular test frequently requires additional consideration.

1. It is necessary that the standard have a reasonably uniform response within the important frequency range of the device under test. Often, in order to achieve this, a particular hydrophone is selected. It is obvious that any irregularity in the response of the standard renders it more difficult to determine accurately response variations in the test instrument in the same frequency range. The situation is even worse if the sound source also has irregularities in this range. For instance, some 3A hydrophones have irregularities in the 20-kc range. By using the OLA hydrophone, which is particularly smooth in this range, to supplement the measurements with the 3A hydrophone, it is possible to improve the accuracy of the calibrations.

2. The output of the hydrophone including its preamplifier should be linear with sound pressure over the frequency range for the range of pressures used in the test. In order to meet this requirement in the measurement of projectors under full power and in tests on underwater sound explosions, it was necessary to use a special 3A shunted down with capacity at the input so that its preamplifier would not overload. Of course, such an instrument has also correspondingly lower response.

3. A hydrophone used as a standard should be low in impedance to reduce the tendency for electric pickup in the leads, or else a preamplifier, preferably of the cathode-follower type, having a low output impedance should be immediately associated with it. The 1A and 2A hydrophones are illustrations of the first type, the 5E and 3A of the latter type.

4. In order to have a uniform response, the hydrophone should not be used near its resonant frequency. This procedure is illustrated by the use of the 1A and 2A hydrophones, which have low-frequency resonances and are used well above their natural frequencies, and by the 5E and 3A hydrophones, which are normally used below their natural frequencies.

5. The hydrophone standards should be nondirective or should have broad beams. It is not always possible to use nondirective instru-

[d] See STR Division 6, Volume 10, Chapter 5.

ments because of interference. Here the 1A and 2A hydrophones, which are of the pressure gradient type and have a directivity pattern which follows a cosine function, are of advantage. In some cases it is more desirable to employ more directive projectors, as, for instance, the 6B or C18. Units which are too directive, however, are undesirable, as they render the testing setup quite critical.

6. In order to be free from electrical interference, it is desirable that the hydrophone electric circuit be balanced to ground and that the sound head be shielded. The shielding is accomplished by enclosing the head in metal (see 3A hydrophones). In cases where this shielding is not provided, it can be added by painting the head with a conducting (metallic) paint. The shield, of course, should be connected to ground. Shielding of the head is more important in fresh water than in sea water, which is highly conductive.

7. When any one of several standards having the same threshold can be used, the one with the higher sensitivity will, in general, be more satisfactory. High sensitivity avoids the necessity for high amplification of the signal, permits the use of amplifiers with higher inherent noise levels, and decreases cross-talk problems. Of course, when high signal pressures are to be measured, low sensitivity may be necessary to avoid overloading the amplifier.

The following table compares the different hydrophone standards which were designed for the USRL by the BTL on NDRC contract.

Hydrophone Standards Used by USRL Designed by BTL on NDRC Contract

Code No.	Type of construction	Frequency range (kc)	Threshold (db)	Directivity index (db)
1A	Moving coil	0.1–30	−40 (1 kc)	Approx. cosine pattern
2A	Moving coil	0.5–150	−32 (25 kc)	Approx. cosine pattern
3A	ADP	0.05–150	−58 (40 kc)	Nondirective up to 15 kc
5C	X-cut Rochelle salt	0.002–10	−75 (10 kc)	−5 (10 kc)
5K	Y-cut Rochelle salt	0.1–40	−75 (10 kc)	−3 (10 kc)
MH	X-cut quartz	100–800	....	−19.5 (150 kc)
MH	X-cut quartz	400–2,300	....	−24.3 (750 kc)

Specific information with respect to these instruments is given in the sections dealing with them.

In addition to the above-mentioned hydrophones, a number of instruments manufactured by other groups in the underwater sound field have been used as standards by the USRL. These include the CMF condenser hydrophone, which has an absolute calibration on a quasi-static basis and is useful for very low frequencies up to 75 c.[a] The HK type hydrophone developed by the Massachusetts Institute of Technology [MIT] was used for low-frequency measurements and has very similar characteristics to the 5C hydrophones. The HK unit using X-cut Rochelle salt crystals, however, does not possess the stability of the types developed later. The B19-B and the OLA instruments have been used at echo-ranging frequencies. The XMX hydrophone developed by MIT is a unit which has proven extremely valuable because it covers such an exceedingly broad frequency range and therefore is especially suited for the measurement of aperiodic sound waves, such as explosions and noises. The XMX hydrophone, however, has a number of disadvantages: (1) It uses X-cut Rochelle salt crystals and thus has to be calibrated each time it is used. Some experimental work has already been done to substitute other crystals. (2) For the same reason, it must be connected to a very high impedance. Since it is very high impedance, even a short length of lead between

[a] See STR Division 6, Volume 10, Chapter 5.

this unit and the receiving amplifier cannot be tolerated. A condenser circuit has been designed by the USRL which can be directly associated with it under water. This circuit provides a high-impedance termination for the crystal and presents a low impedance to the cable. (3) It is insufficiently shielded, which has caused electric pickup trouble in some tests. This lack of shielding has been overcome by painting the head with metallic paint. These defects are minor and can readily be overcome, as illustrated.

1.4 STANDARD INSTRUMENTS

1.4.1 5A Projector

Type: ADP Crystal.
Operating range: 20 to 150 kc.
Designer: Bell Telephone Laboratories.
Manufacturer: Western Electric Company.
Reference: NDRC Report No. 6.1-sr783-1329, February 7, 1945.[38]
Description: Consists of a crystal transducer unit and a transformer in a common housing. The transducer unit contains an array of ammonium dihydrogen phosphate crystals mounted between the diaphragm, which is exposed to the water, and a steel backing plate. It is designed to work from a circuit having 135 ohms impedance. The projector, except for the diaphragm end, is encased in a layer of low-impedance sound-reflecting cork and rubber material. A 30-ft shielded, flexible, 2-conductor, rubber-covered cord is provided for connecting the projector to the sound source. For schematic circuit drawing, see Figure 33 in Section 1.4.6.

Overall diameter: 2⅞ in.
Overall length: 7 in.
Weight: 9 lb.

Recommended maximum power input: 0.1 w from a 135-ohm source.
Efficiency: Approximately —18.5 db vs ideal at 70 kc.

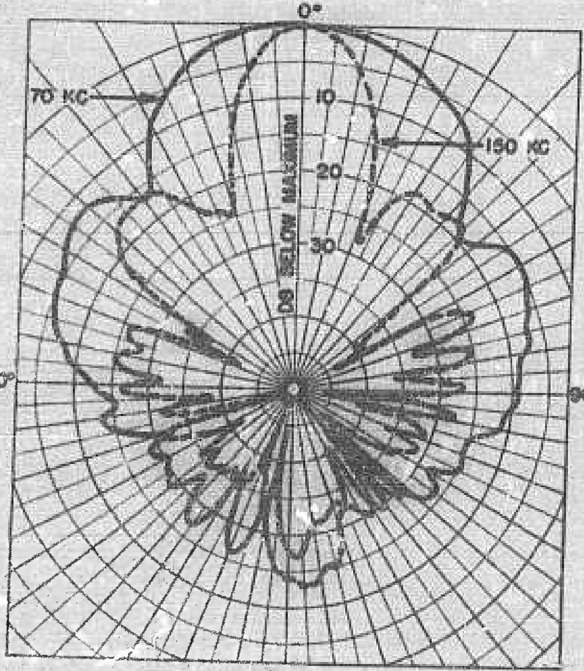


FIGURE 1. Directivity patterns, 5A projector.

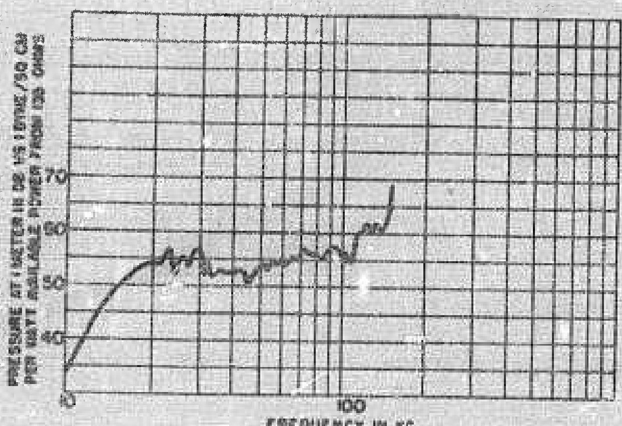


FIGURE 2. Transmitting response, 5A projector.

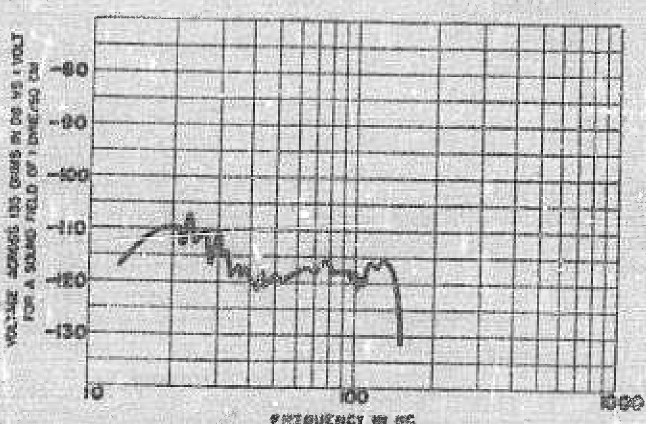


FIGURE 3. Receiving response, 5A projector.

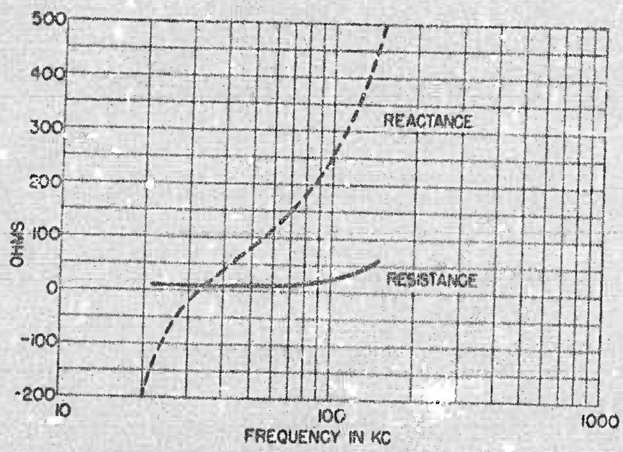


FIGURE 4. Impedance, 5A projector.

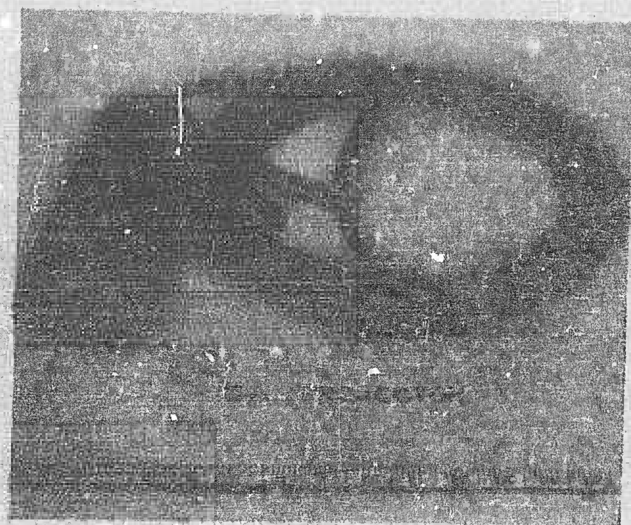


FIGURE 5. 5A projector.

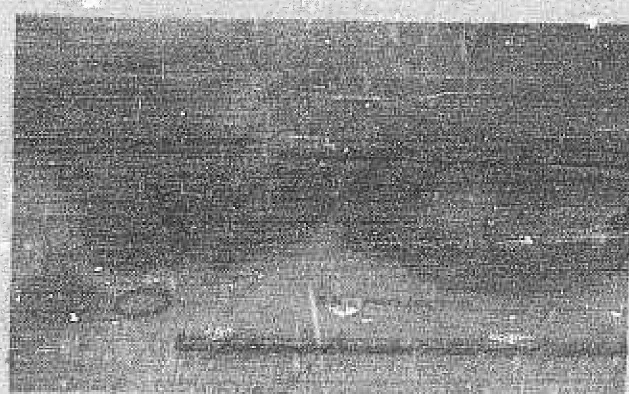


FIGURE 6. 5A projector, interior view.

1.4.2

AX-124 Projector (AX-70)

Type: ADP Crystal.
Operating range: 5 to 100 kc.
Designer: Brush Development Company.
Reference: USRL Orlando Project 135A, November 21, 1944 to December 2, 1944.
Description: This projector, a small model of the AX-63 (see Section 2.7.40), is designed for maximum output in the region 40 to 50 kc. The crystal assembly is split along a vertical axis, and four separate terminal connections are brought out from the transducer. The unit is oil-filled so that it may be used at depths of several hundred feet. This model supersedes an earlier one, the AX-70, which used X-cut Rochelle salt crystals.
Efficiency: Approximately −2 db vs ideal at 55 kc.

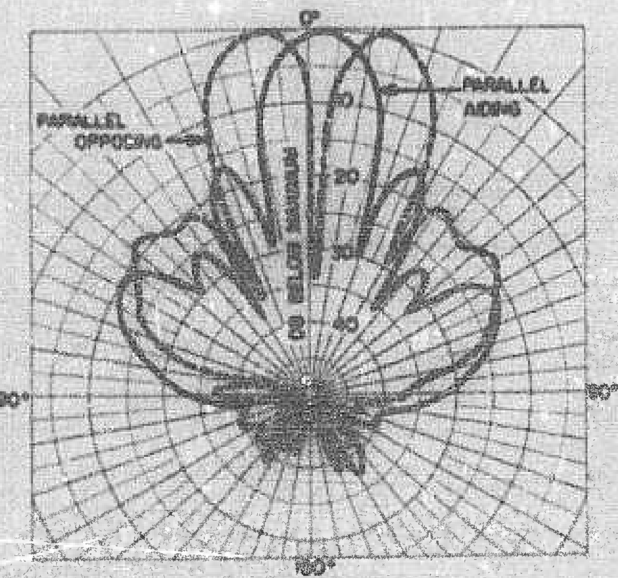


FIGURE 7. Directivity patterns, AX-124 projector at 55 kc.

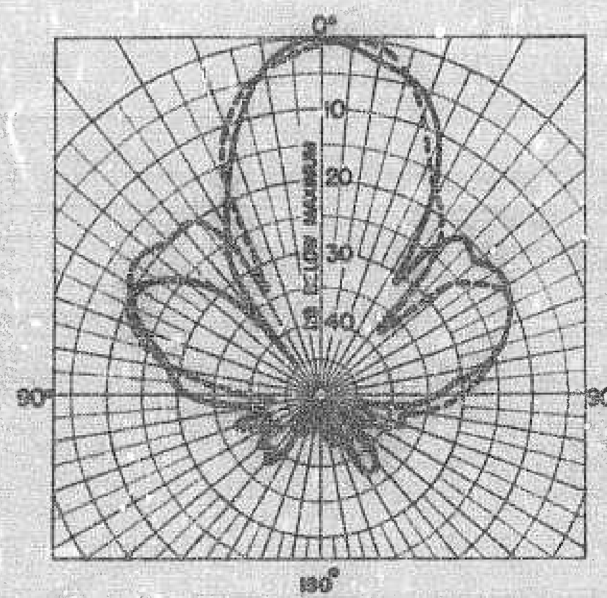


FIGURE 8. Directivity patterns, AX-124 projector at 55 kc. Each half measured separately.

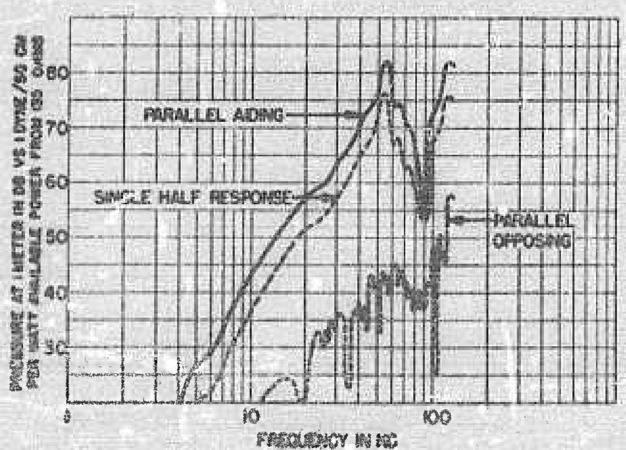


FIGURE 9. Transmitting response, AX-124 projector.

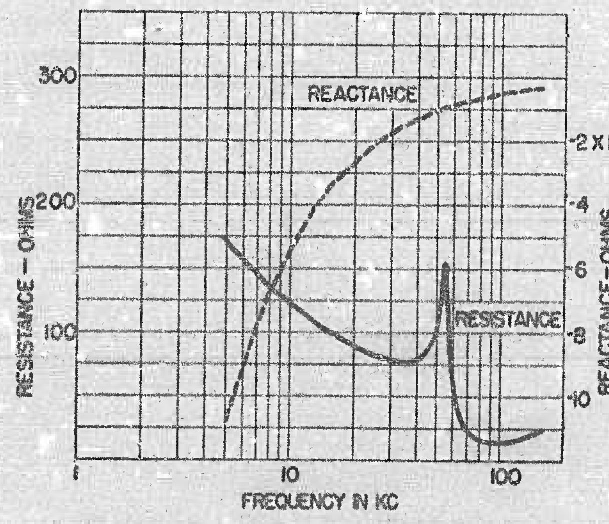


FIGURE 12. Impedance, AX-124 projector.

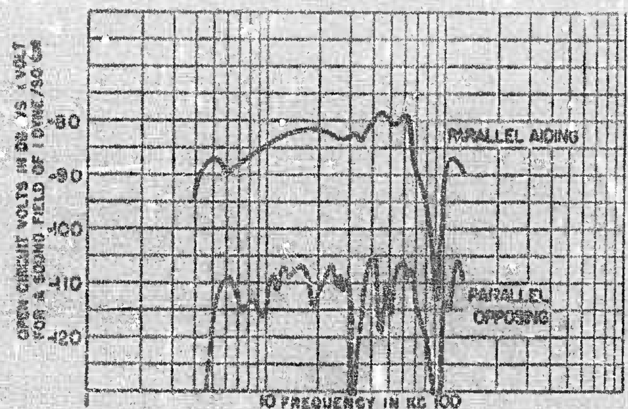


FIGURE 10. Receiving response, AX-124 projector.

FIGURE 13. AX-124 projector.

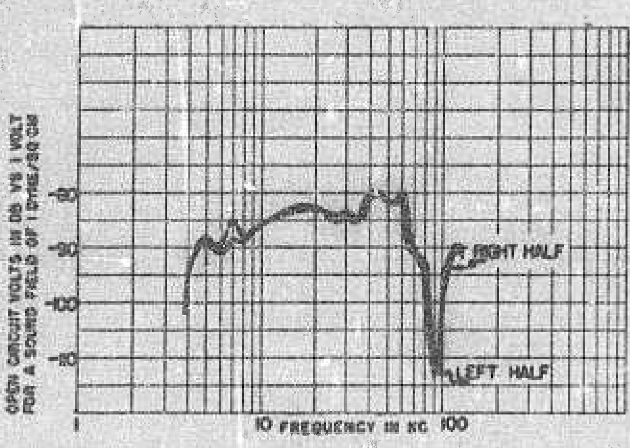


FIGURE 11. Receiving response, AX-124 projector. Each half measured separately.

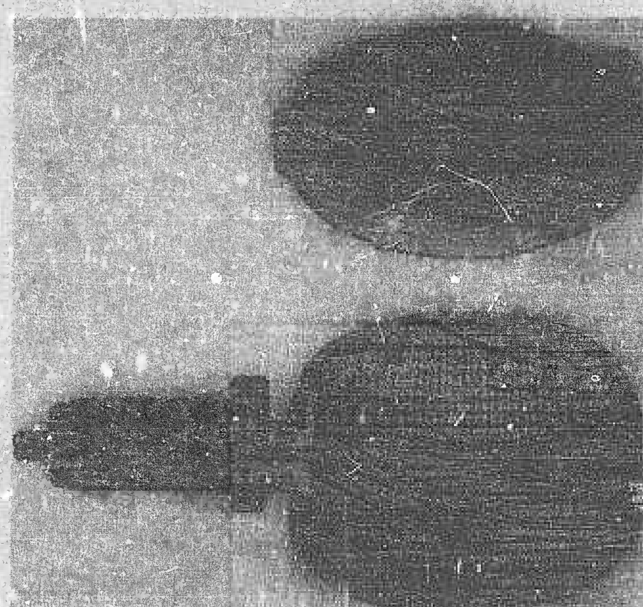


FIGURE 14. AX-124 projector, interior view.

1.4.3

2B Projector

Type: Y-Cut Rochelle Salt Crystal.
Operating range: 7.5 to 28 kc.
Designer: Bell Telephone Laboratories.
Manufacturer: Western Electric Company.
References: NDRC Report No. 6.1-sr212-625, January 21, 1943.[15]
NDRC Report No. 6.1-sr20-602, January 27, 1943.[16]

Description: A multiunit resonant system using five crystal blocks, each covering about 20 per cent of the frequency range. Each block consists of quarter wavelength, 45° Y-cut Rochelle salt crystals, backed by a quarter wavelength steel resonator. The crystal blocks are enclosed in a chamber filled with castor oil. Sound is radiated into the water through a rubber dome which forms part of the oil chamber. The rear cover of the unit encloses an air chamber containing resonating coils and a step-down transformer.

Overall diameter: 20 in.
Overall length: 15 in.
Weight: 217 lb.

Recommended maximum power input: 6 or 8 w.
Efficiency: —3 db at 23 kc.

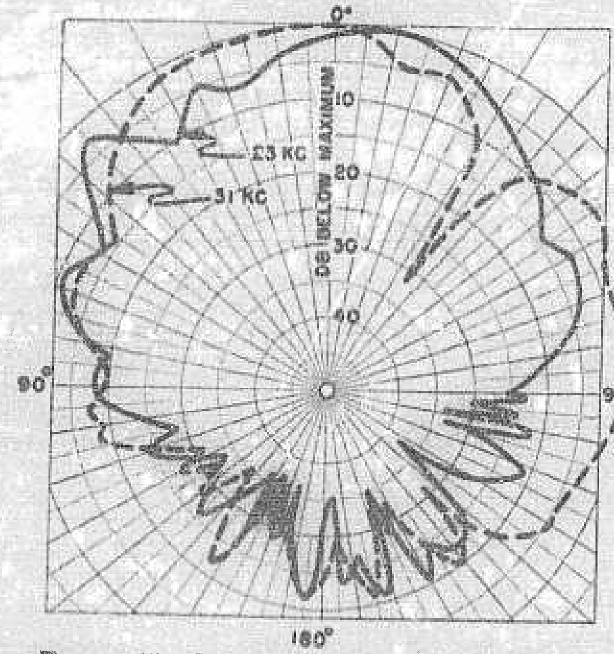


FIGURE 15. Directivity patterns, 2B projector.

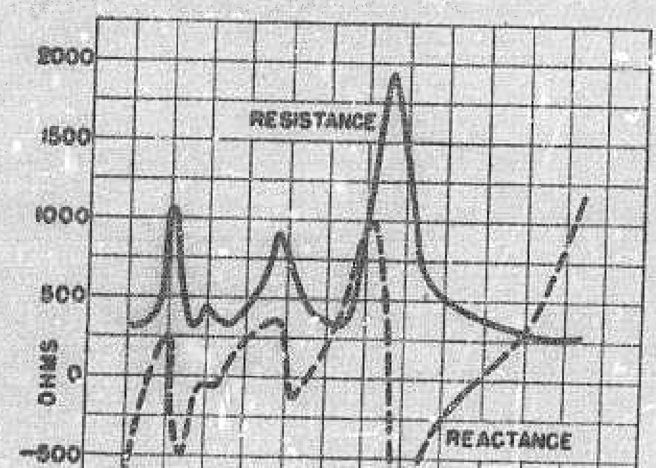


FIGURE 16. Impedance, 2B projector.

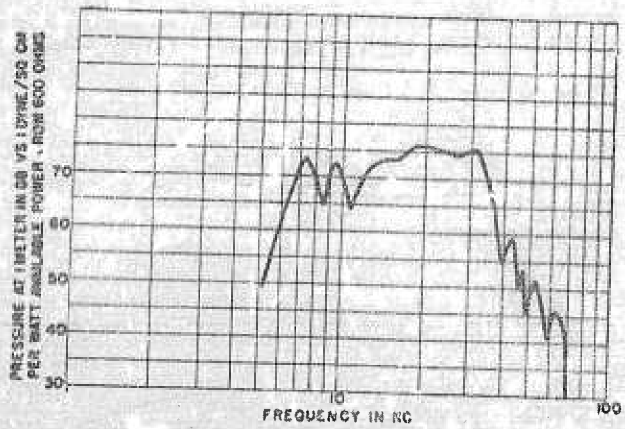


FIGURE 17. Transmitting response, 2B projector.

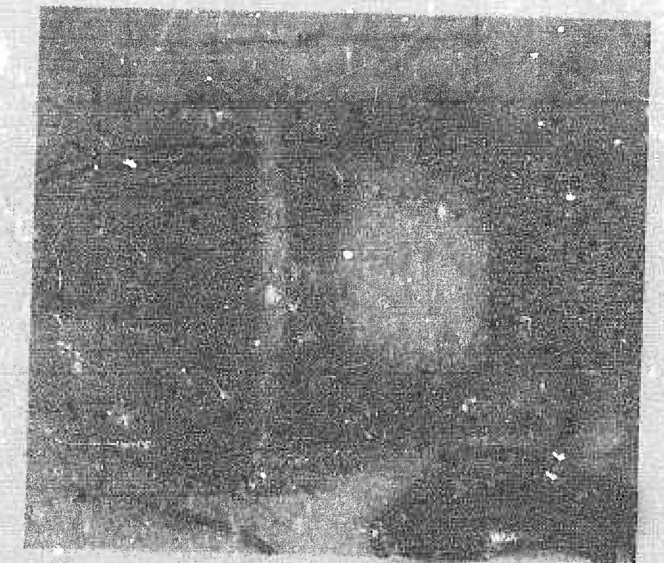


FIGURE 18. 2B projector.

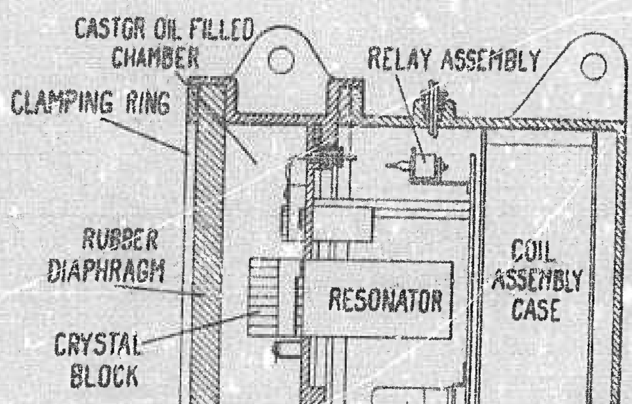


FIGURE 19. 2B projector, assembly cross section.

1.4.4

3B Projector

Type: Y-Cut Rochelle Salt Crystal.
Operating range: 28 to 100 kc.
Designer: Bell Telephone Laboratories.
Manufacturer: Western Electric Company.
References: NDRC Report No. 6.1-sr212-625, January 21, 1943.[15]
NDRC Report No. 6.1-sr20-602, January 27, 1943.[16]
Description: Similar in principle and construction to BTL 2B projector.
Overall diameter: 14 in.
Overall length: 16 in.
Weight: 124 lb.

Recommended maximum power input: Varies with frequency from about 0.5 w at 100 kc to 5 w at 25 kc.

Efficiency: Approximately —3 db at 40 kc.

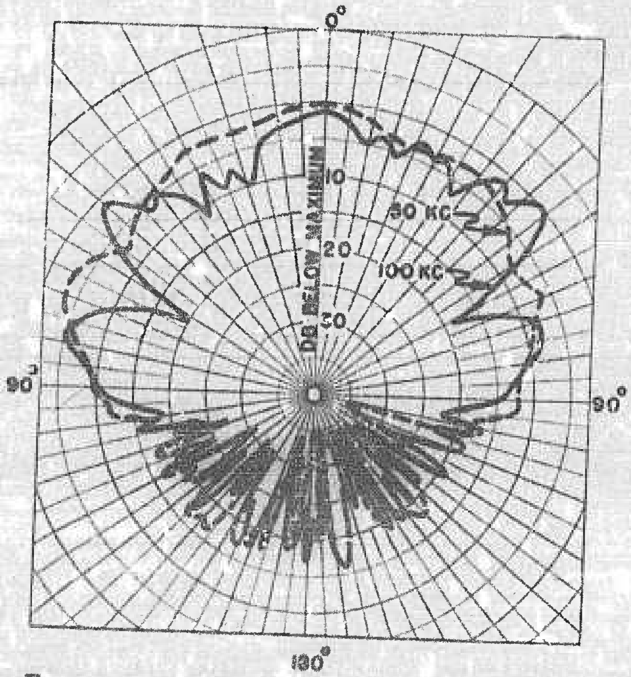


FIGURE 20. Directivity patterns, 3B projector.

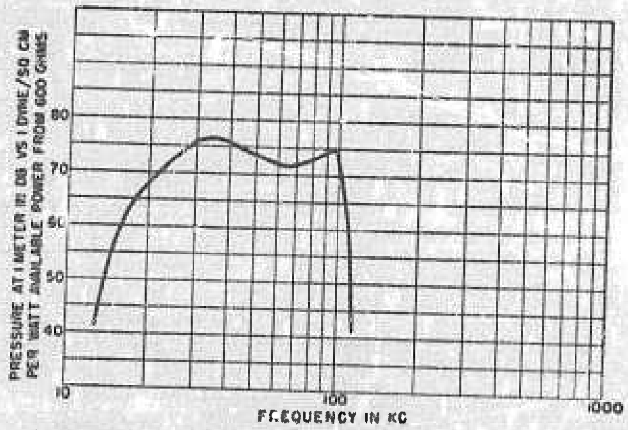


FIGURE 22. Transmitting response, 3B projector.

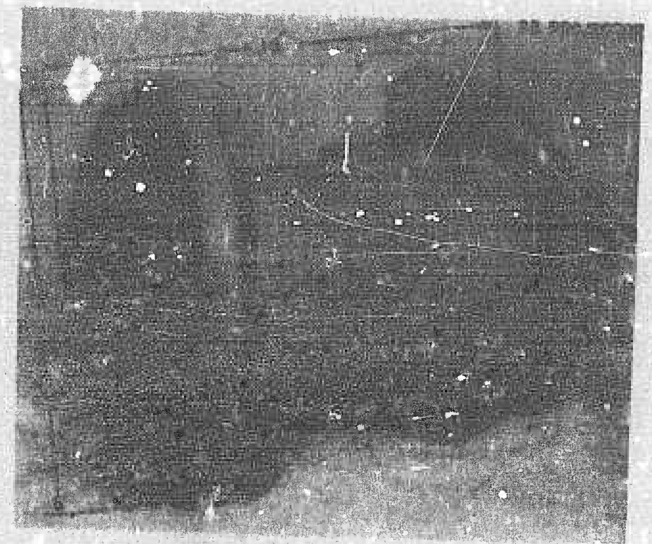


FIGURE 23. 3B projector.

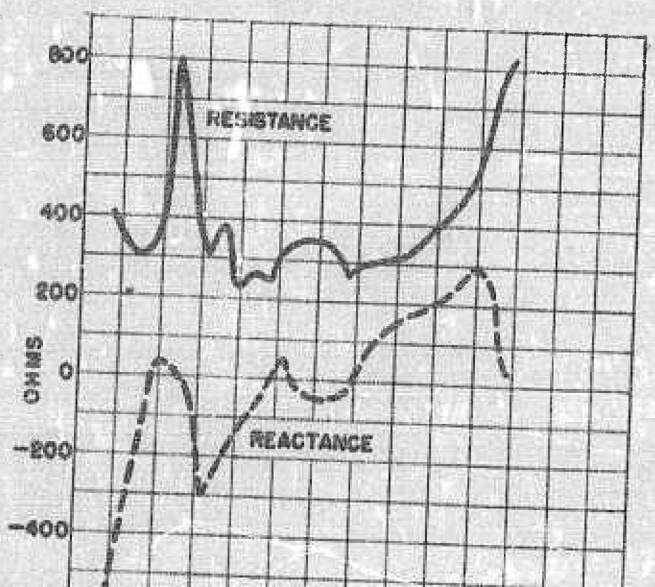


FIGURE 21. Impedance, 3B projector.

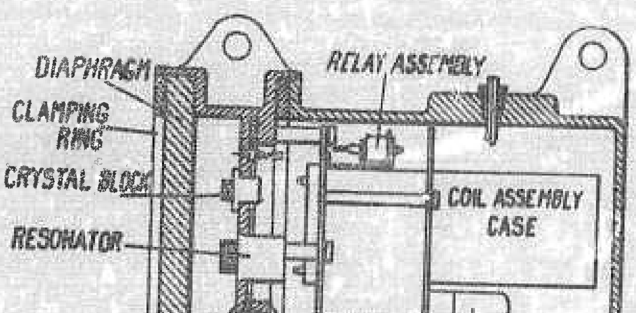


FIGURE 24. 3B projector, assembly cross section.

1.1.5 **4B Projector**

Type: Inertia Controlled Moving Coil.

Operating range: 8 to 500 c.

Designer: Bell Telephone Laboratories.

Manufacturer: Western Electric Company.

Reference: NDRC Report No. 6.1-sr783-1213, November 20, 1943.[27]

Description: The vibrating surface is an annular-shaped beryllium-copper diaphragm covered by a watertight rubber membrane and driven by a large moving coil positioned in the field of a permanent magnet. The magnet and the diaphragm are enclosed in a cast bronze housing with one side of the diaphragm exposed to the water through an opening 9 in. in diameter. A high-pressure reservoir at the rear of the projector automatically supplies air to the rear of the diaphragm to compensate for the external water pressure.

Outside diameter: Approximately 16 in.

Weight: 375 lb.

Recommended maximum power input: 125 w from a 16-ohm source.

Efficiency: Approximately −30 db vs ideal.

Directional properties: Essentially nondirective in operating frequency range.

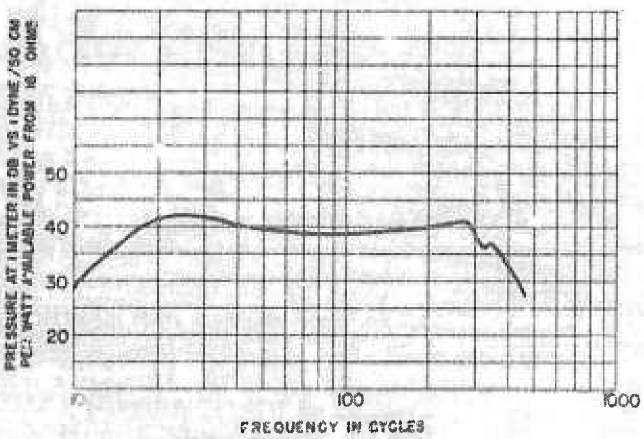


FIGURE 25. Transmitting response, 4B projector.

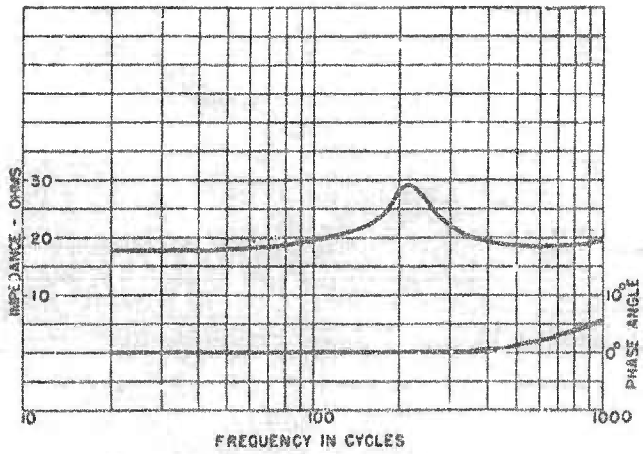


FIGURE 26. Impedance, 4B projector.

FIGURE 27. 4B projector.

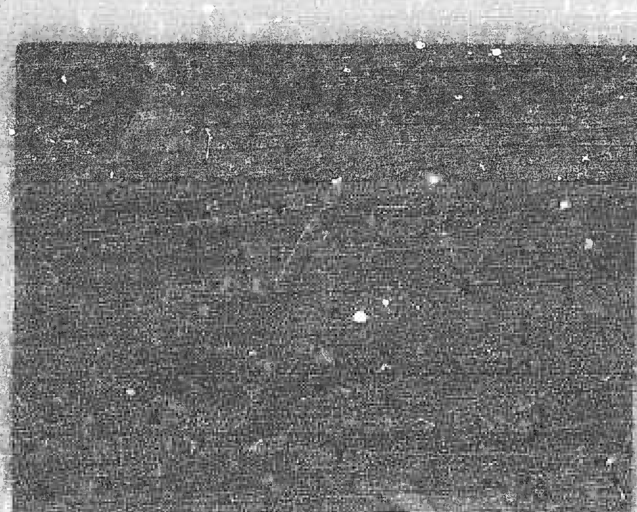


FIGURE 28. 4B projector, interior view.

1.4.6 6B Projector

Type: Y-Cut Rochelle Salt Crystal.
Operating range: 10 to 80 kc.
Designer: Bell Telephone Laboratories.
Manufacturer: Western Electric Company.
Reference: NDRC Report No. 6.1-sr783-1325, August 10, 1944.[55]

Description: The diaphragm is driven by an array of 45° Y-cut Rochelle salt crystals connected in parallel. The crystal array is mounted between the diaphragm and a steel backing plate. The rear half of the crystal head assembly is enclosed in a casing of a low-impedance, sound-reflecting, cork and rubber material. It is designed to work from a circuit having 135 ohms impedance. A transformer is included in the housing to deliver the power from the low-impedance source to the high-impedance crystal array. A 25-ft shielded, flexible, 2-conductor, rubber-covered cord is provided for connecting the projector to the power source.

Overall diameter of head: 6¼ in.
Overall height: 19½ in.
Weight: 30 lb.

Recommended maximum power input: 0.1 w from a 135-ohm source.
Efficiency: Approximately −16 db vs ideal at 70 kc.

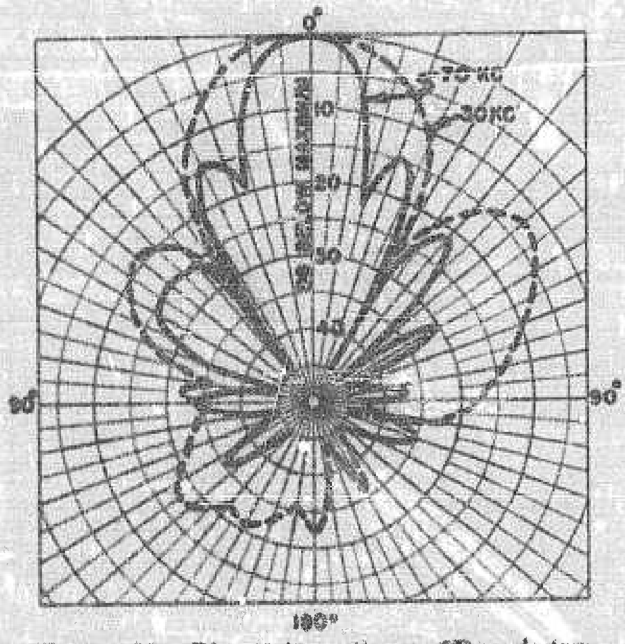


FIGURE 29. Directivity patterns, 6B projector.

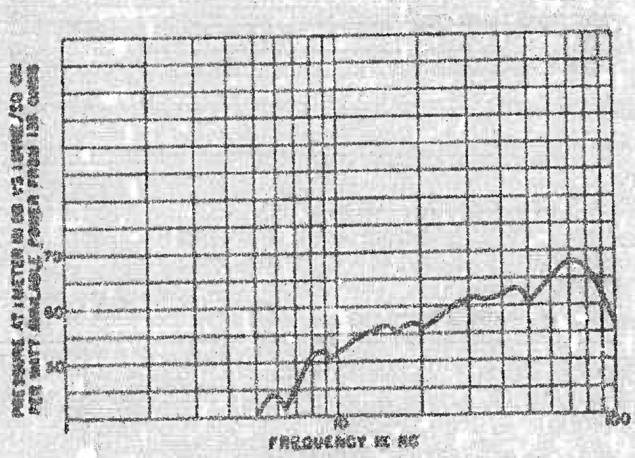


FIGURE 30. Transmitting response, 6B projector.

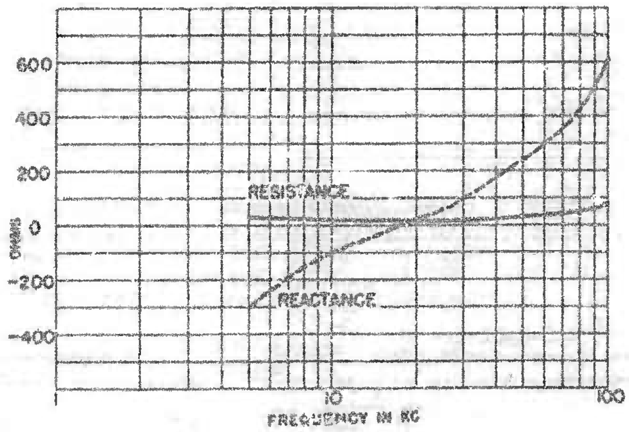


FIGURE 31. Impedance, 6B projector.

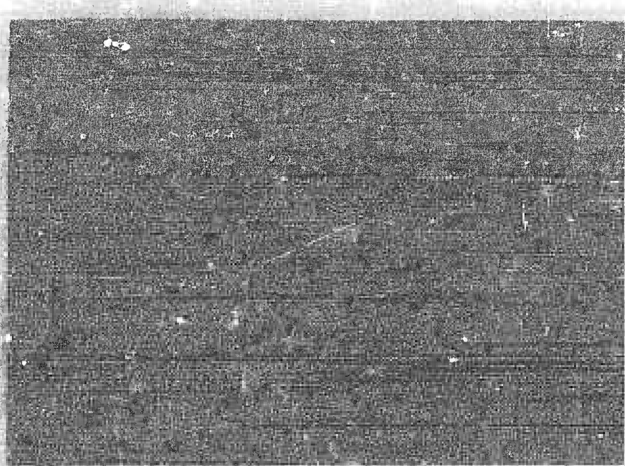


FIGURE 32. 6B projector.

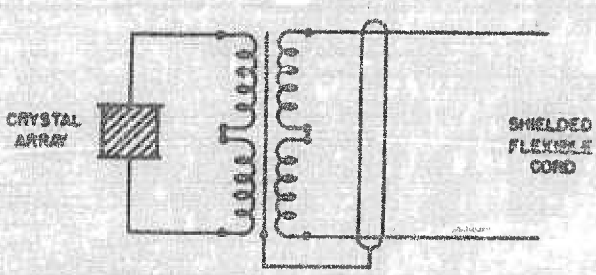


FIGURE 33. Schematic circuit drawing, 6B and 5A projectors.

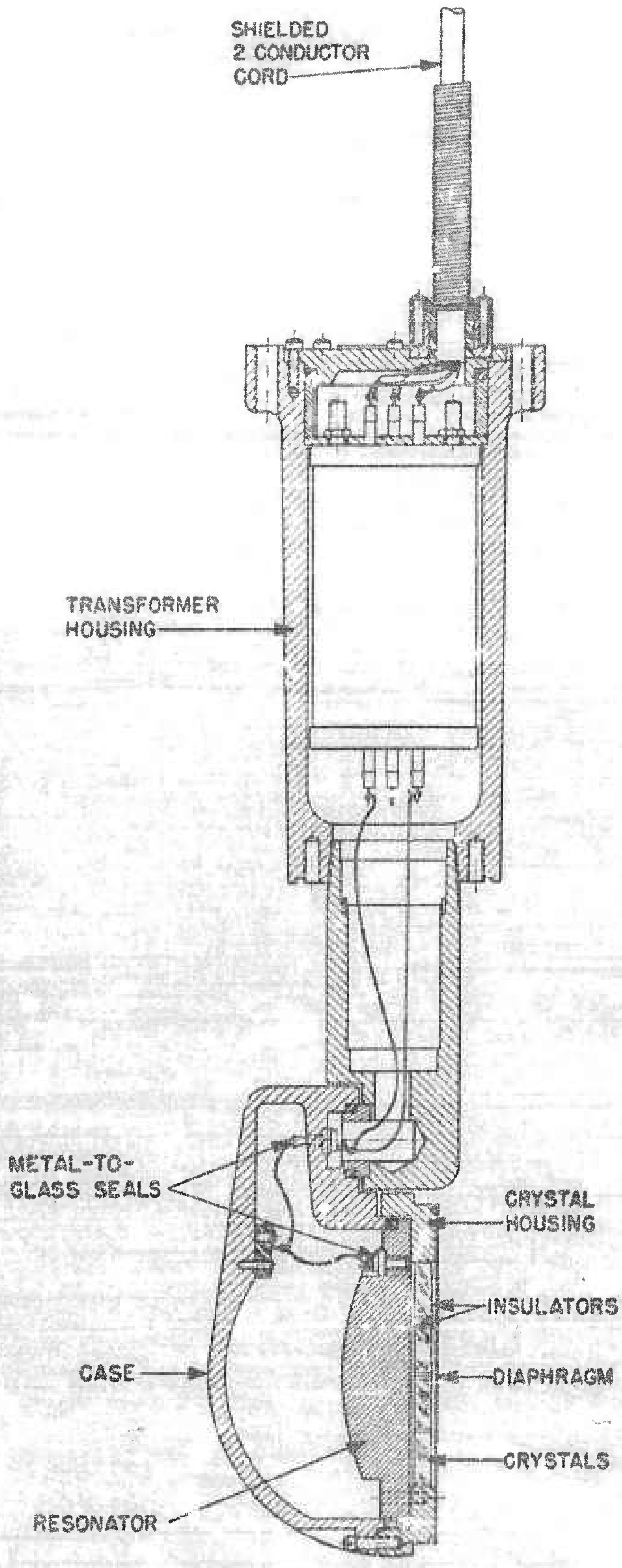


FIGURE 34. 6B projector, assembly cross section.

1.6.7 1K Projector

Type: Inertia Controlled Moving Coil.
Operating range: 100 to 10,000 c.
Designer: Bell Telephone Laboratories.
Manufacturer: Western Electric Company.
Reference: NDRC Report No. C4-sr212-103, June 1, 1942.[6]

Description: The sound radiating surface is a small piston-type diaphragm with a rigid center and flexible edge. The rigid center, a portion of a hemispherical dome of beryllium-copper, is driven at its outer perimeter by a moving coil in a high-density magnetic field. The motion of the diaphragm is controlled by the combined mass of the vibrating system and the loading mass of the water. A rubber compensating chamber automatically maintains internal air pressure to balance the external water pressure at the diaphragm. The unit is designed to work from a circuit having 4 ohms impedance.

Greatest width: 17 in.
Overall height: 45 in.
Weight: 150 lb.

Recommended maximum power input:

Frequency (c)	4-ohm source		8-ohm source	
	RMS open-circuit voltage	Available power (w)	RMS open-circuit voltage	Available power (w)
100	8.0	4	9.4	2.75
200	8.0	4	9.0	2.5
400	17.9	20	21.6	14.5
800 and above	17.9	20	21.6	14.5

Efficiency when operating from a 4-ohm source: —26 db vs ideal at 400 c.

Directional properties: Nondirectional up to about 2,000 c. Above this frequency, uniform through an angle of ±45° from the axis of the diaphragm.

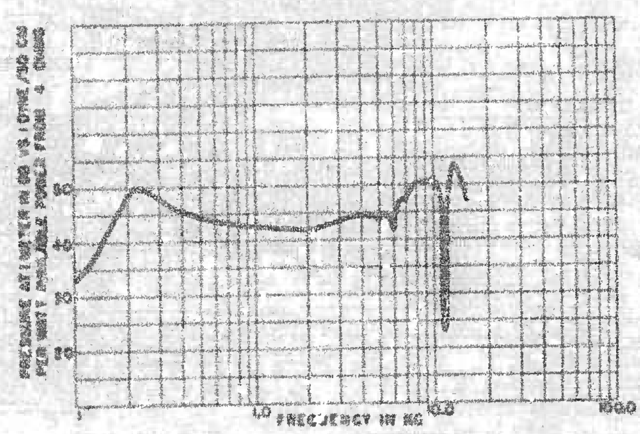


FIGURE 35. Transmitting response, 1K projector.

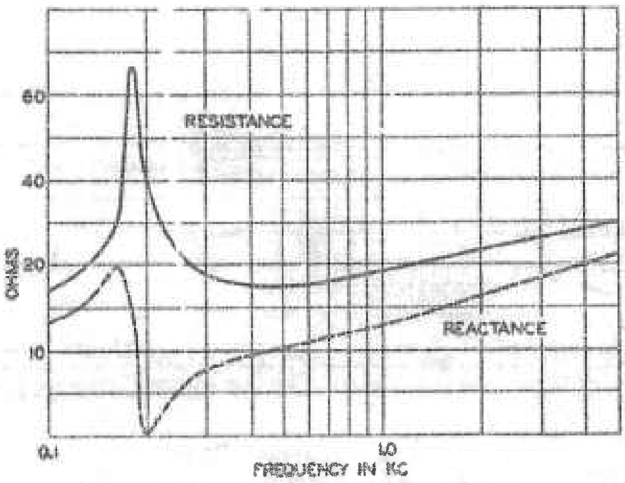


FIGURE 36. Impedance, 1K projector.

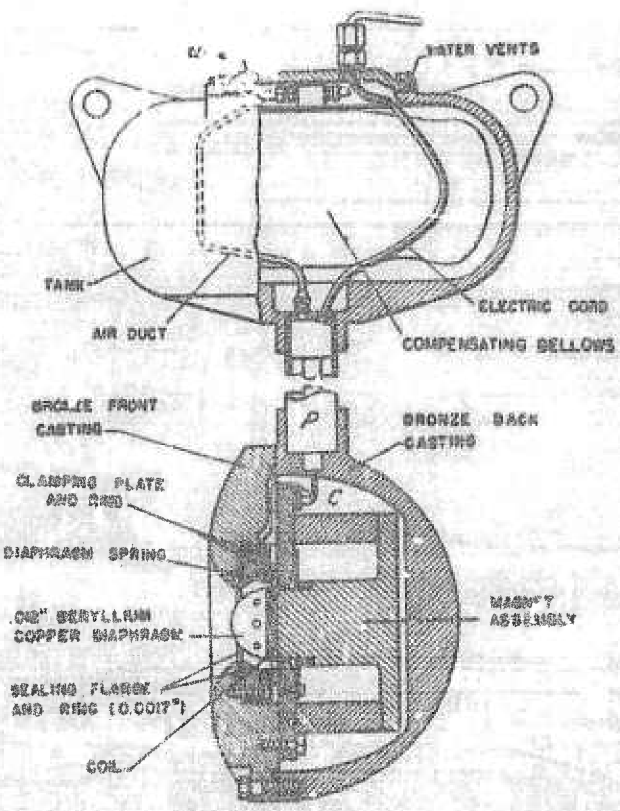


FIGURE 37. 1K projector, assembly cross section.

FIGURE 38. 1K projector.

1.18 C13 Transducer

Type: X-Cut Rochelle Salt Crystal.
Operating range: 5 to 150 kc.
Designer: Brush Development Company.
Reference: Brush Report No. LR-118, September 9, 1943.[25]
Description: An array of X-cut Rochelle salt crystals form a radiating area approximately 3 in. square. The unit is oil-filled, which permits its use at submerged depths of several hundred feet without appreciable change in characteristics.
Recommended maximum power input: Because of the use of X-cut crystals, performance depends on the external circuit used. For stable operation a constant current circuit is required.
Efficiency: —18.5 db at 70 kc.

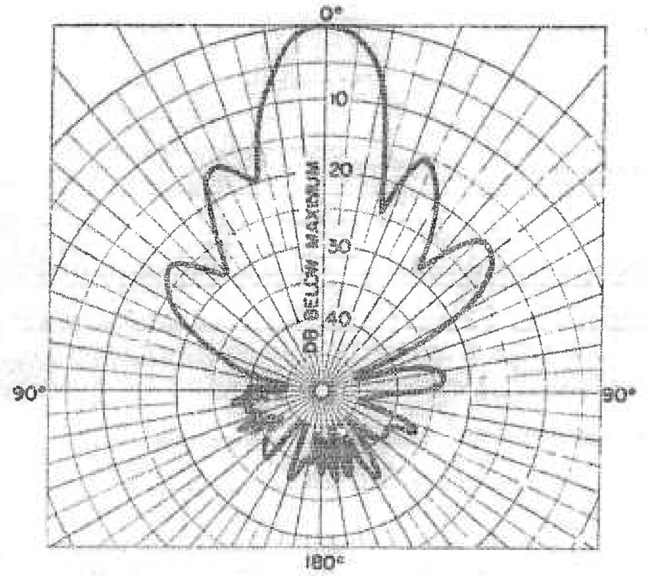


FIGURE 39. Directivity patte , C13 projector at 70 kc.

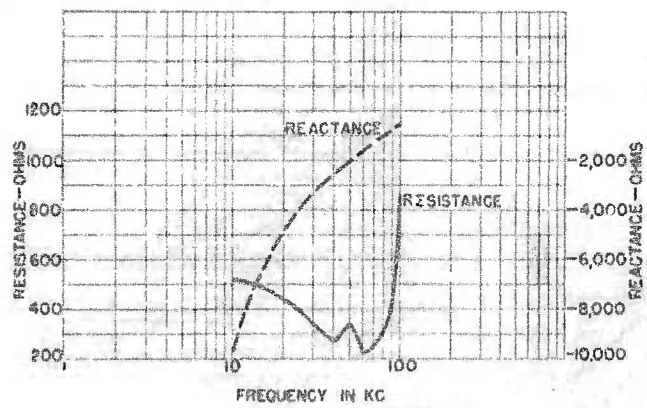


FIGURE 41. Impedance, C13 projector.

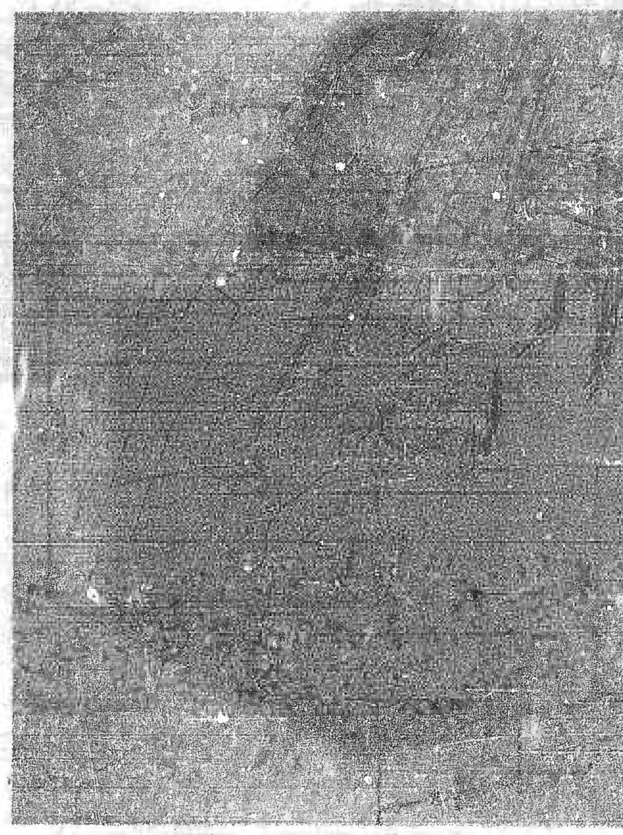


FIGURE 42. C13 projector.

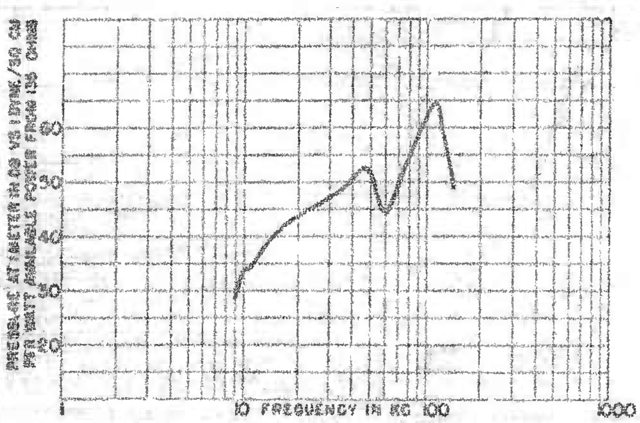


FIGURE 40. Transmitting response, C13 projector.

1.4.9 MH Transducers

Type: X-Cut Quartz Crystal.

Operating range: 100 to 2,000 kc.

Designer: Bell Telephone Laboratories. Designed as part of an ultrasonic hydrophone calibration system.

Manufacturer: Western Electric Company.

Reference: NDRC Report No. 6.1-sr783-1697, August 17, 1944.[36]

Description: There are two sets of transducers, one for the 100- to 800-kc range, and one for the 300- to 2,200-kc range. The crystal assembly consists of two X-cut quartz crystal disks, silver-treated and soldered one on each surface of a steel disk. One side of the assembly vibrates against air, the other against a layer of castor oil separated from the water by a diaphragm. The crystal disks are 1 cm in diameter in the 300- to 2,200-kc instruments, and 3 cm in diameter in the 100- to 800-kc instruments.

Recommended maximum power input: 3 w.

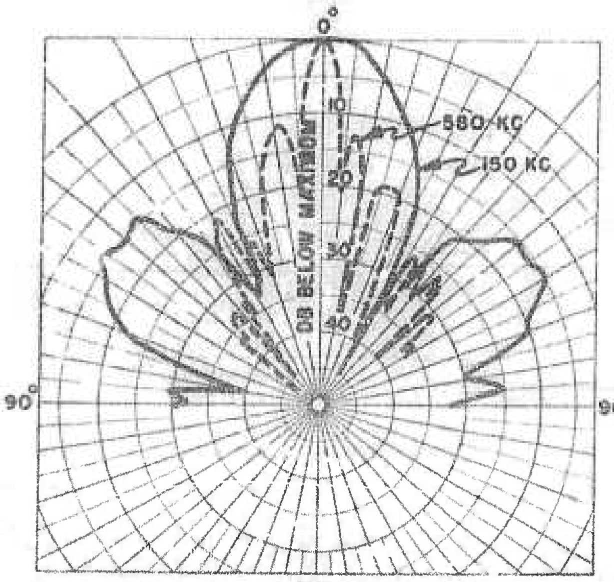


FIGURE 43. Directivity patterns, MH transducer.

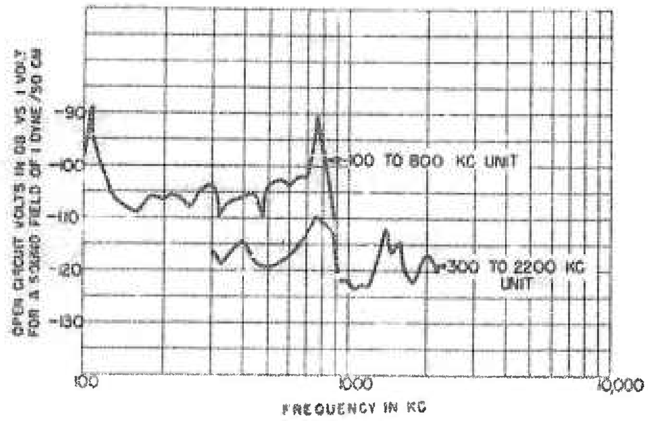


FIGURE 45. Receiving response, MH transducer.

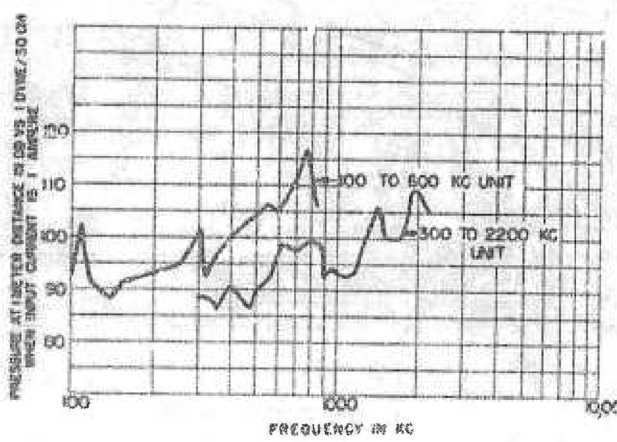


FIGURE 44. Transmitting response, MH transducer.

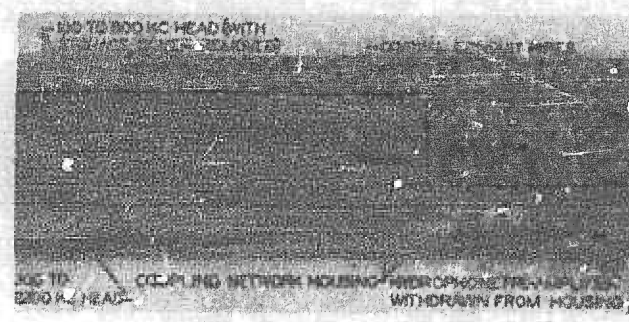


FIGURE 46. MH transducer.

1.4.10

1A Hydrophone

Type: Pressure Gradient Moving Coil.

Operating range: 100 to 50,000 c.

Designer: Bell Telephone Laboratories.

Manufacturer: Western Electric Company.

Reference: NDRC Report No. C4-sr212-058, March 2, 1942.[3]

Description: A coil consisting of many turns of fine wire wound on a rectangular bakelite form is movable in the field of a permanent magnet assembly. The entire instrument is suspended by springs in a container of thin copper foil with a vulcanized coating of tough rubber. The container is filled with an air-free liquid which freezes at 8 F, and which contains ethyl alcohol and glycerin in such proportions that the acoustic impedance closely matches that of water. Twenty-five feet of shielded, rubber-covered cord is connected to the hydrophone. As much as 300 ft of such cord may be used between hydrophone and amplifier without appreciable loss or distortion.

Overall dimensions of case: 2x2½x6 in.

Weight: 3 lb.

Directional properties: In a plane perpendicular to the long axis, the directivity has a cosine pattern up to about 40 kc. Maximum response is obtained when the direction of propagation of the sound is in the plane of the coil normal to the longer side.

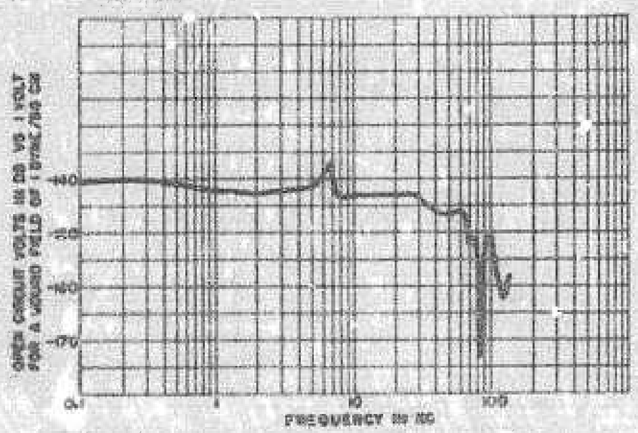


FIGURE 47. Receiving response, 1A hydrophone.

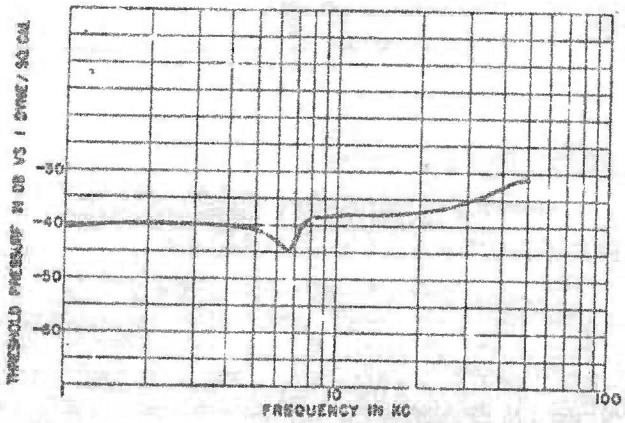


FIGURE 48. Calculated threshold, 1A hydrophone.

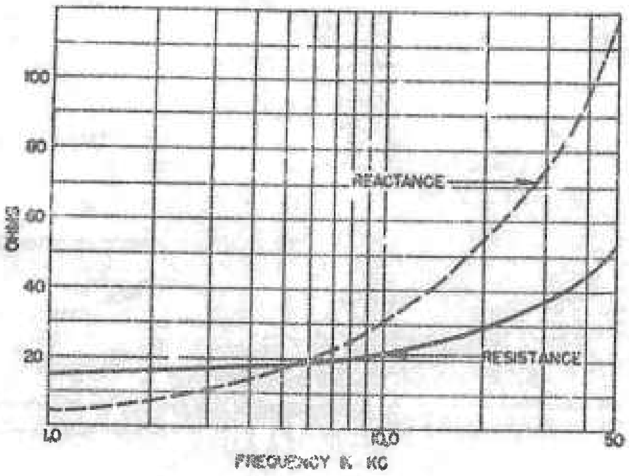


FIGURE 50. Impedance, 1A hydrophone.

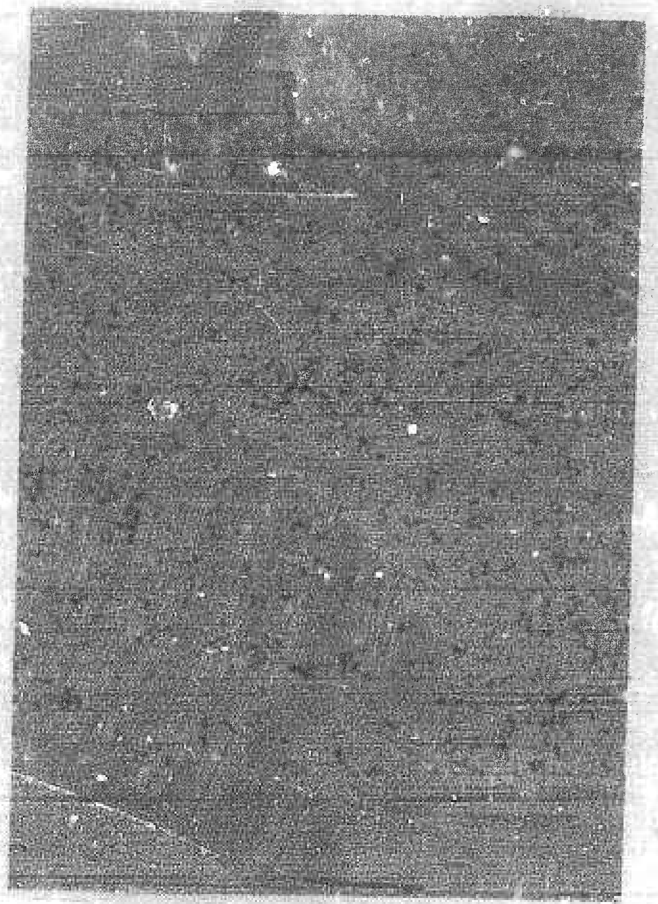


FIGURE 49. 1A hydrophone.

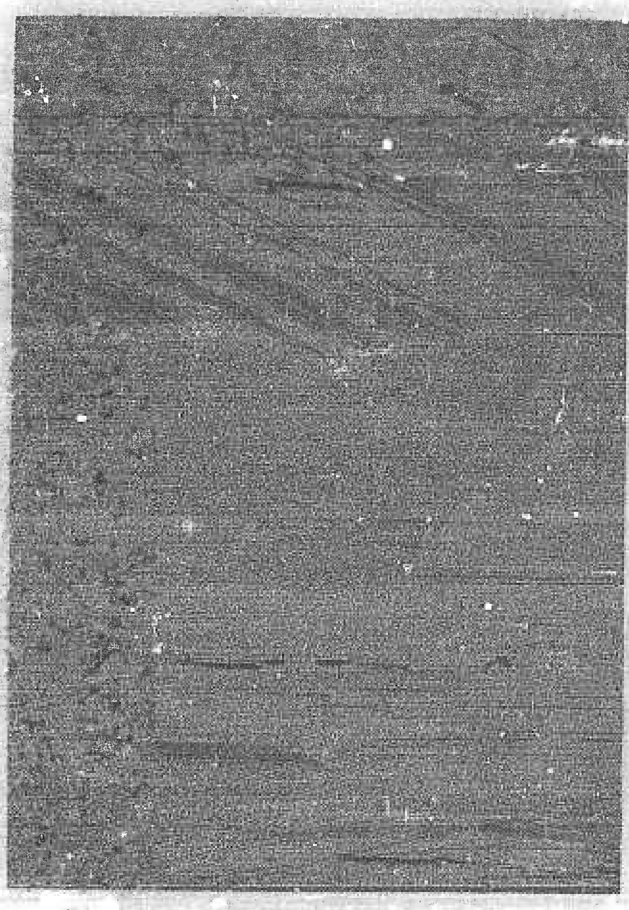


FIGURE 51. 1A hydrophone, interior view.

1.4.11

2A Hydrophone

Type: Pressure Gradient Moving Coil.
Operating range: 500 to 100,000 c.
Designer: Bell Telephone Laboratories.
Manufacturer: Western Electric Company.
Reference: USRL Mountain Lakes Project 250A.

Description: A smaller model of the 1A hydrophone mounted in the same size housing. The container is filled with an air-free liquid which freezes at 8 F. Twenty-five feet of shielded, rubber-covered cord is connected to the hydrophone. As much as 300 ft of such cord may be used between hydrophone and amplifier without appreciable loss or distortion.

Overall dimensions of case: 2x2½x6 in.

Weight: 3 lb.

Directional properties: In a plane perpendicular to the long axis, the directivity has a cosine pattern up to about 70 kc. Maximum response is obtained when the direction of propagation of the sound is in the plane of coil normal to the longer side.

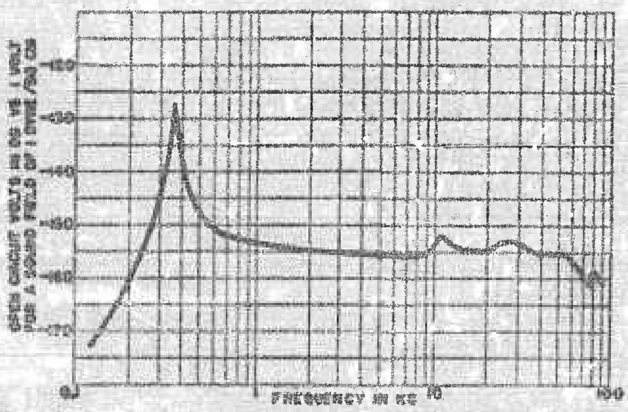


FIGURE 52. Receiving response, 2A hydrophone.

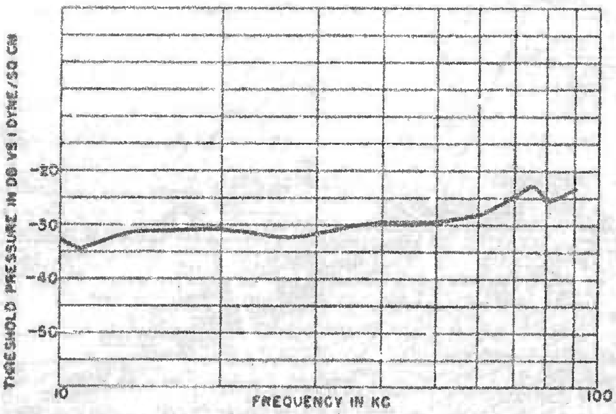


FIGURE 53. Calculated threshold, 2A hydrophone.

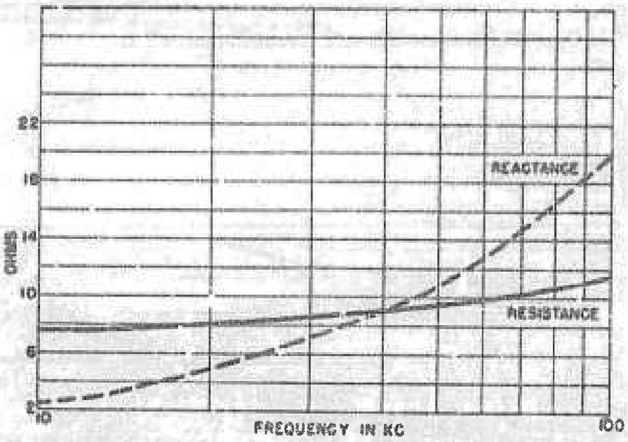


FIGURE 55. Impedance, 2A hydrophone.

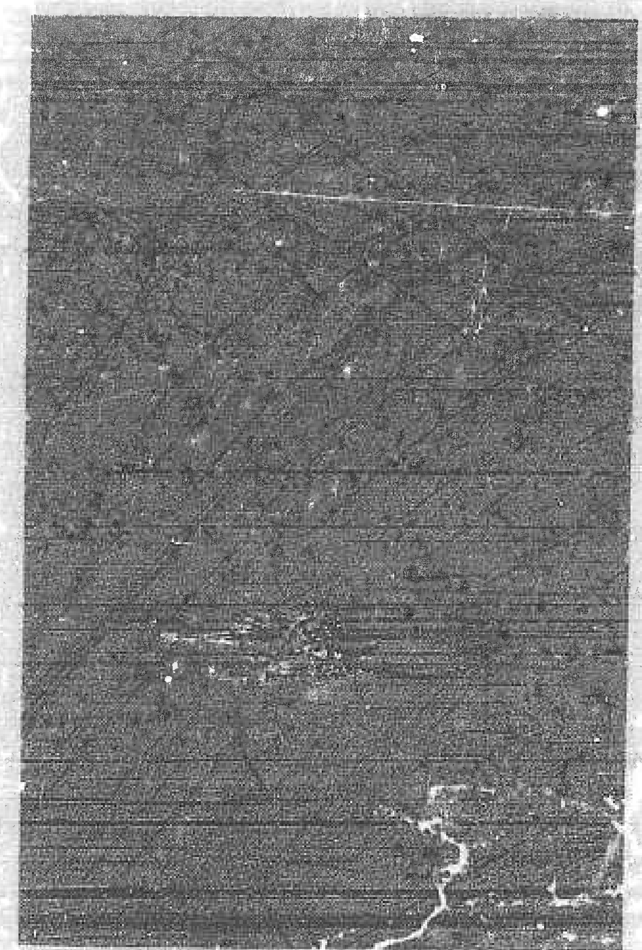


FIGURE 54. 2A hydrophone.

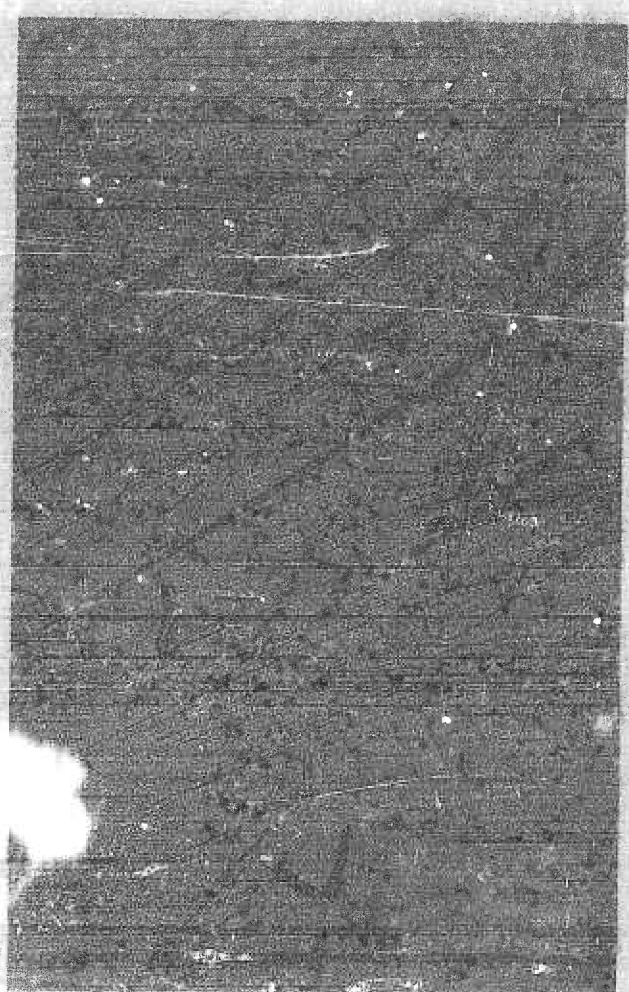


FIGURE 56. 2A hydrophone, interior view.

1.4.12

3A Hydrophone

Type: Z-Cut ADP Crystal.

Operating range: 50 to 150,000 c.

Designer: Bell Telephone Laboratories.

Manufacturer: Western Electric Company.

Reference: NDRC Report No. C4-sr212-507, October 1, 1942.[14]

Description: The latest design uses four 45° Z-cut ADP crystals connected in parallel and mounted between two diaphragms. The two-stage preamplifier is enclosed in a monel metal housing. The amplifier is designed to work into a 600-ohm load or transmission line. A 25-ft, 4-conductor, shielded cable is supplied with the hydrophone. The maximum output voltage that this amplifier can deliver into 600 ohms without overloading is approximately 0.2 v, which corresponds to an applied pressure of about 5,000 to 10,000 dynes per sq cm. The original design employed Y-cut Rochelle salt crystals. A special 3A hydrophone for high-pressure measurements was constructed by shunting the crystal head with a 0.004 μf condenser. This increased the maximum measurable pressure to 10^{6} dynes per sq cm but reduced the response by over 50 db (to about −140 db vs 1 v across 600 ohms per dyne per sq cm).

A guard is provided for the crystal head. This guard introduces rather severe irregularities above 20 kc and in general it is desirable to avoid its use in testing. If [illegible] must be attached, special care should be taken to assure that it is fr[illegible] bubbles.[f]

Overall width: [illegible].

Overall length: 1[illegible] in.

Diameter of crystal head: ¾ in.

Directional properties: Response independent of direction of sound incidence at frequencies less than 15,000 c. Above 15,000 c diffraction affects the response when the direction of sound incidence is normal to the diaphragm (at 0°) and it is preferable to use the instrument so that the direction of the sound is parallel to the face (90°).

[f] See STR Division 6, Volume 10, Chapter 6.

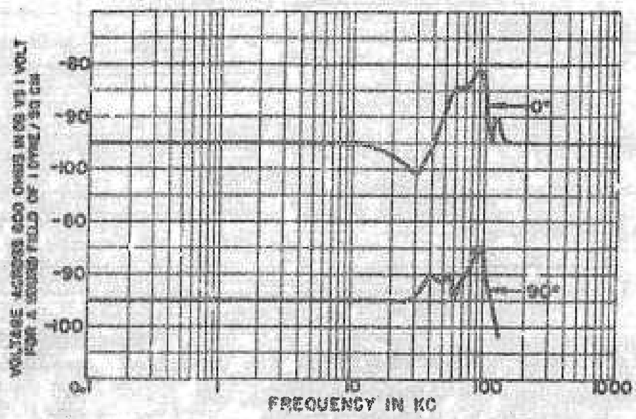


FIGURE 57. Receiving response, 3A hydrophone.

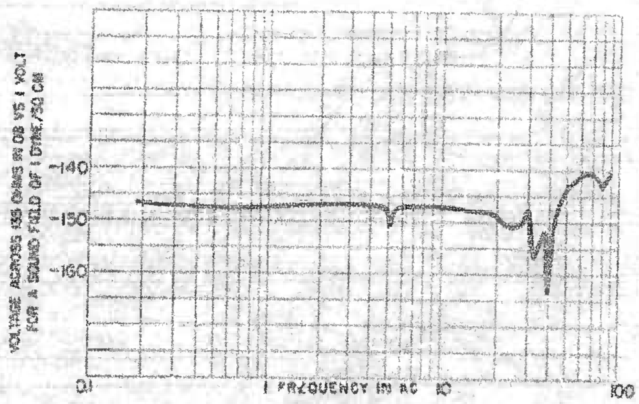


FIGURE 60. Receiving response, special 3A hydrophone. Crystal head shunted with an 0.004 μf condenser.

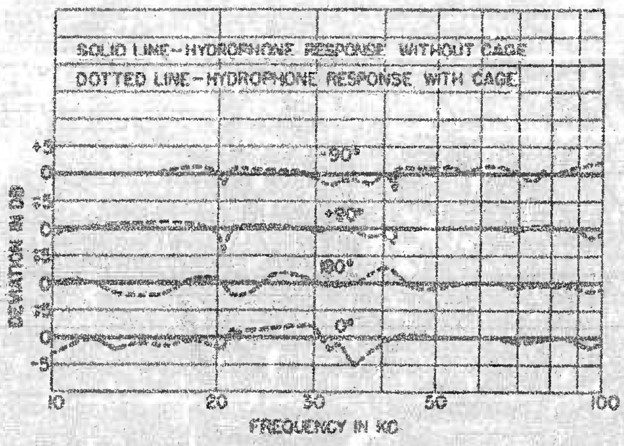


FIGURE 58. Effect of guard on response of 3A hydrophone.

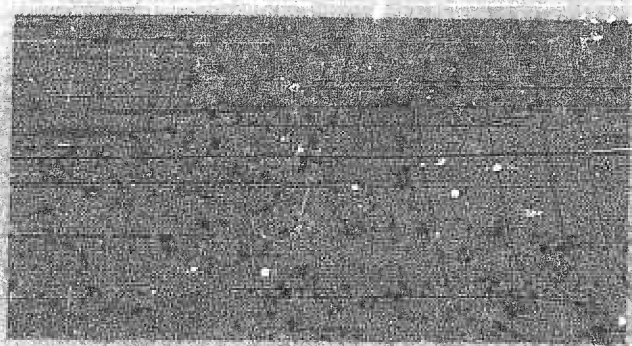


FIGURE 61. 3A hydrophone.

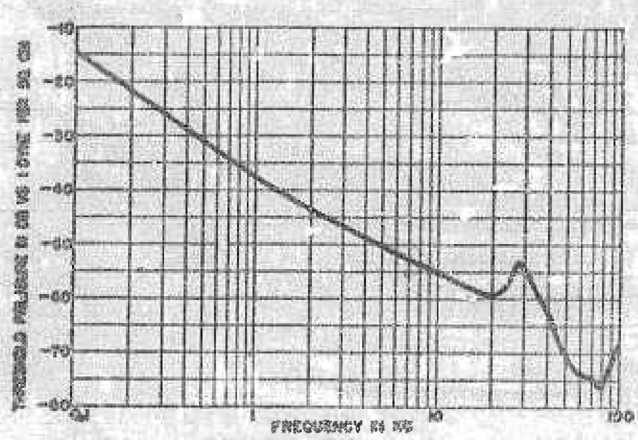


FIGURE 59. Measured threshold, 3A hydrophone.

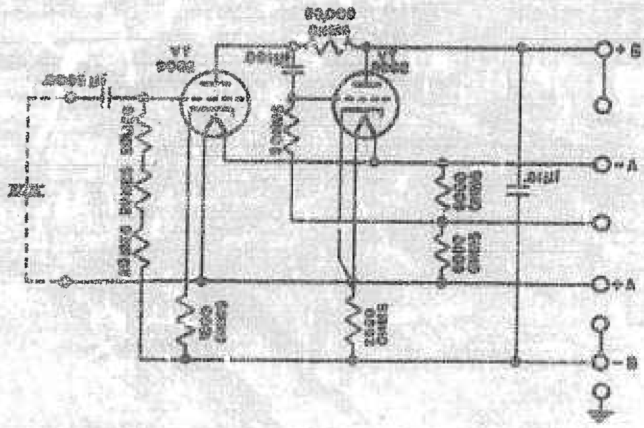


FIGURE 62. Circuit schematic, 3A hydrophone.

1.4.18

AX-91 Hydrophone

Type: ADP Crystal.

Operating range: 100 to 100,000 c.

Designer and Manufacturer: Brush Development Company.

Reference: USRL Orlando Project 154A, February 5, 1945 to February 12, 1945.

Description: This hydrophone is similar to the C11-A1 hydrophone, except that it includes some structural improvements in the assembly of the amplifier and head.

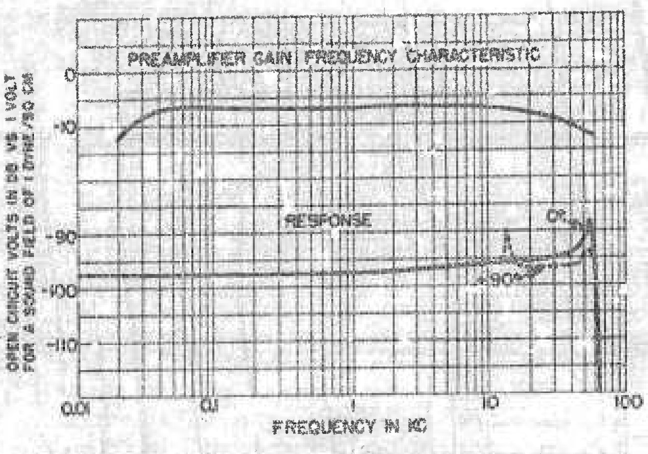


FIGURE 63. Receiving response, AX-91 hydrophone.

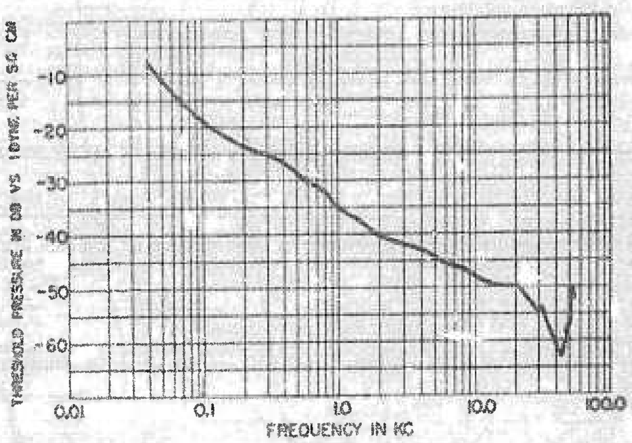


FIGURE 64. Measured threshold, AX-91 hydrophone.

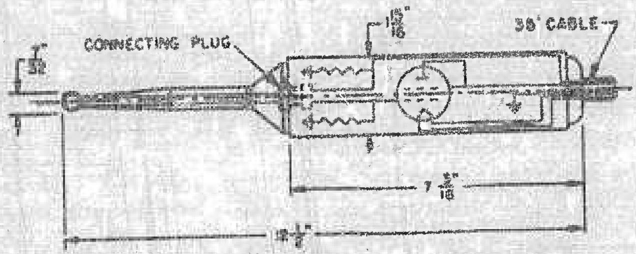


FIGURE 65. AX-91 hydrophone.

1.4.14 B19-B Hydrophone

Type: Magnetostriction.

Operating range: 200 to 100,000 c.

Designer: Harvard Underwater Sound Laboratory.

Reference: NDRC Report No. 6.1-sr1130-1199, January 17, 1944.[39]

Description: The transducer consists of a nickel tube 35 mils in thickness, 5¾ in. in length by 1½ in. in diameter, with a permanent magnet of Alnico metal inside. A semicylindrical wooden core is placed on each side of the magnet, and a coil consisting of 130 turns of No. 26 wire is wound lengthwise over the core and magnet. The ends of the nickel tube are closed by caps fastened together with tie rods. At one end the hydrophone cable is brought out through a watertight gland. Suspension yokes are attached to the end caps.

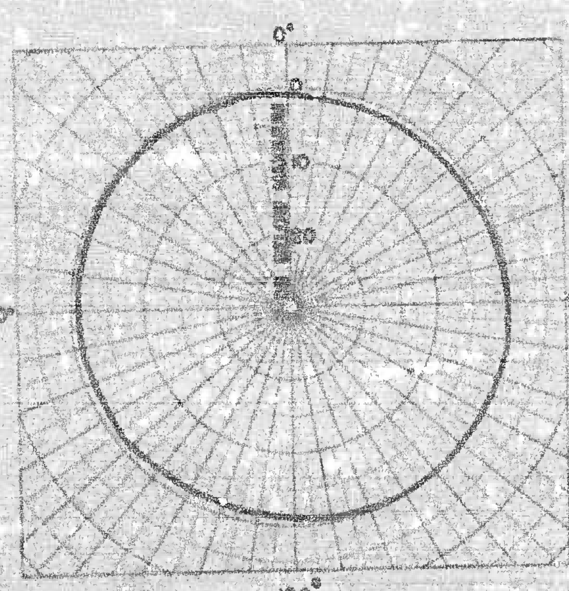


FIGURE 66. Directivity pattern, B19-B hydrophone at 20 kc in a plane perpendicular to the axis.

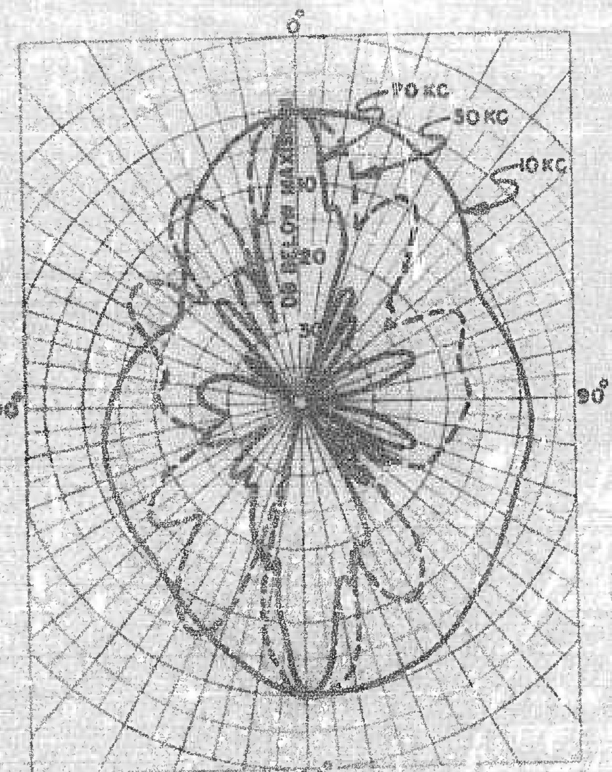


FIGURE 67. Directivity pattern, B19-B hydrophone at 70 kc in a plane containing the axis.

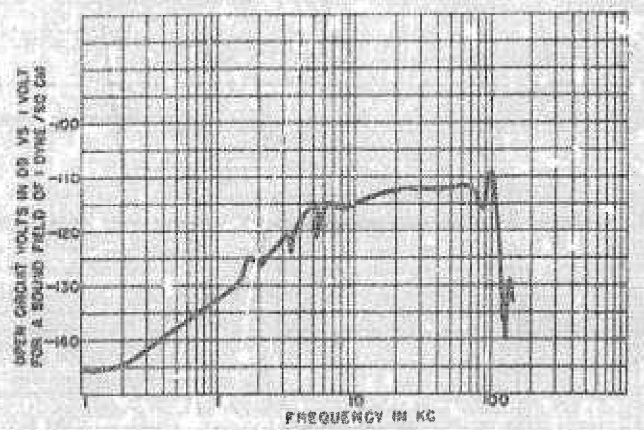


FIGURE 68. Receiving response, B19-B hydrophone.

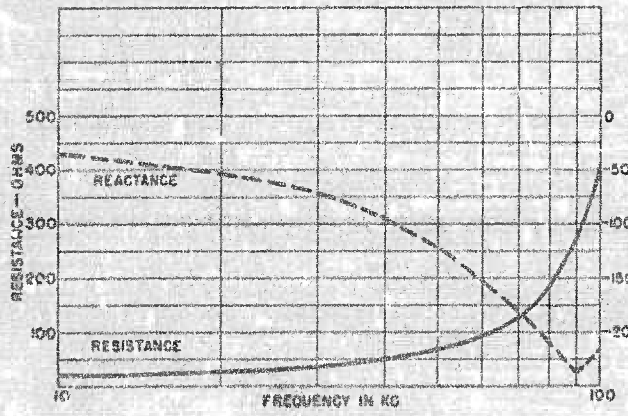


FIGURE 70. Impedance, B19-B hydrophone.

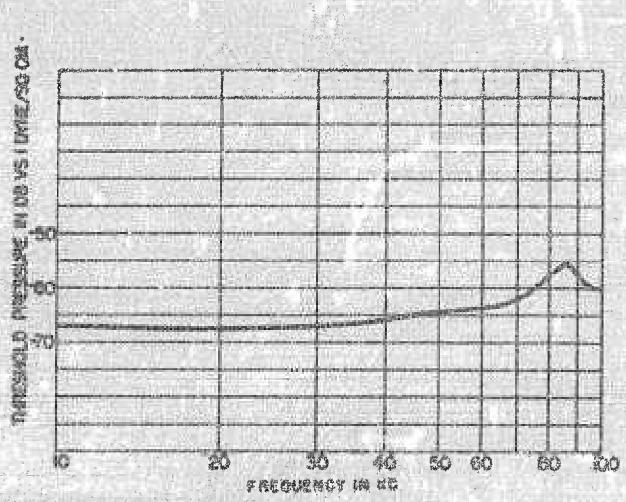


FIGURE 69. Calculated threshold, B19-B hydrophone.

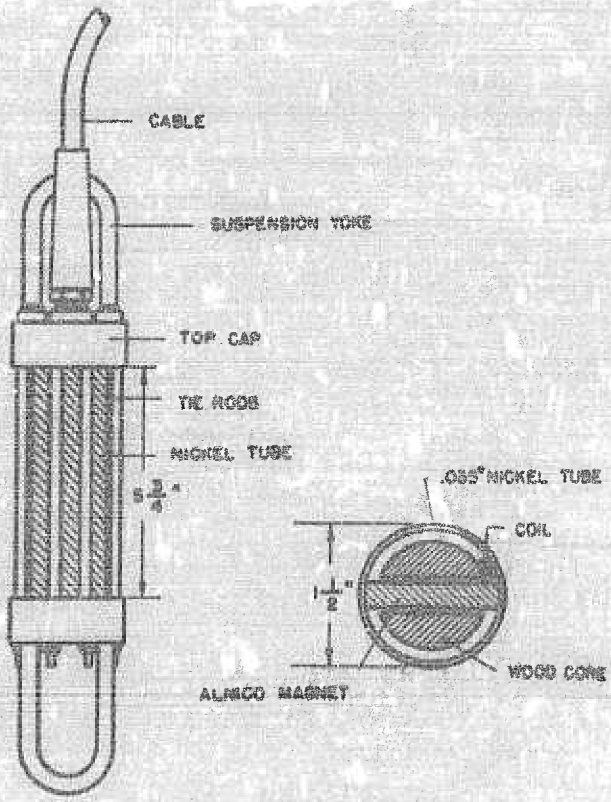


FIGURE 71. B19-B hydrophone.

1.4.15 B19-H Monitor Hydrophone

Type: Magnetostriction.

Operating range: 200 to 100,000 c.

Designer: Harvard Underwater Sound Laboratory.

Reference: NDRC Report No. 6.1-sr1130-1826, August 28, 1944.[70]

Description: This unit differs from the B19-B type hydrophone in that the tube has a diameter of ¾ in. and a 25-mil annealed nickel wall as compared to 1½ in. and a 35-mil nickel wall for the B19-B unit. The magnetostriction assembly is the same as that of the B19-B except that the solid Alnico magnet is replaced by four or five 15-mil laminations of Cunico.

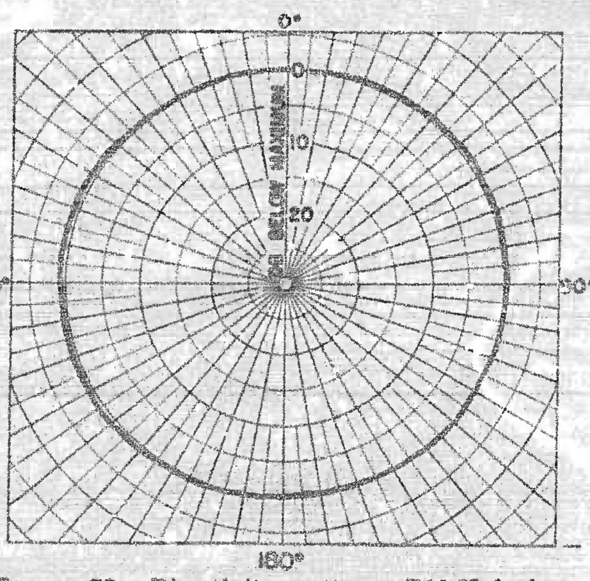


FIGURE 72. Directivity pattern, B19-H hydrophone at 40 kc in a plane perpendicular to the axis.

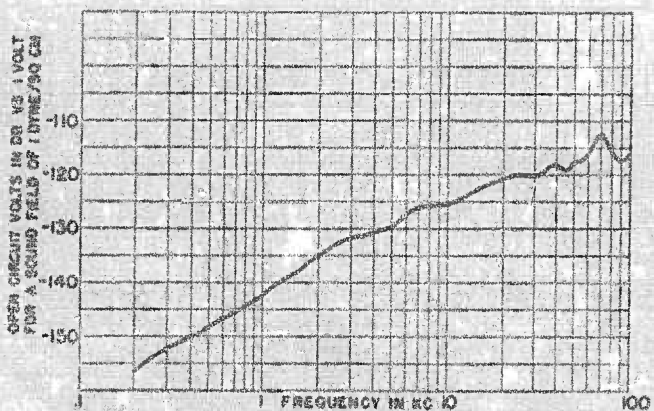


FIGURE 73. Receiving response, B19-H hydrophone.

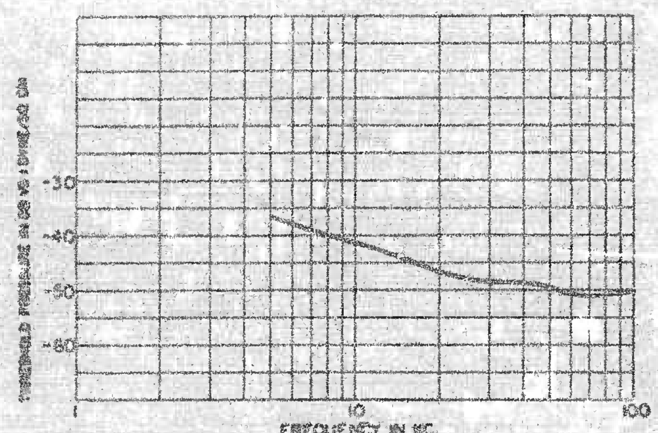


FIGURE 74. Calculated threshold, B19-H hydrophone.

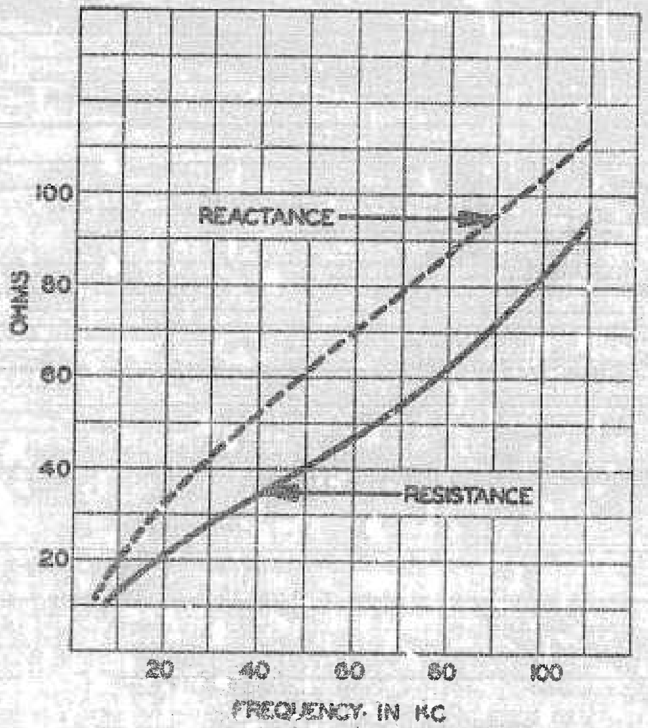


FIGURE 75. Impedance, B19-H hydrophone.

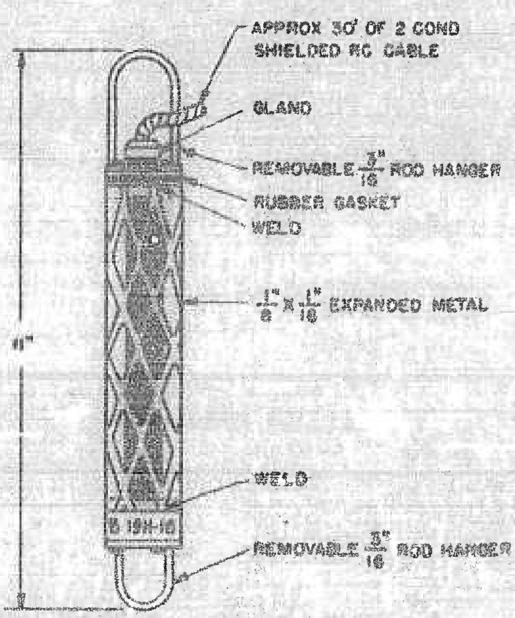


FIGURE 76. B19-H hydrophone.

1.4.16 5C and 5E Hydrophones

Type: 5C Hydrophone: X-Cut Rochelle Salt Crystal.
5E Hydrophone: Y-Cut Rochelle Salt Crystal.

Operating range: 5C Hydrophone: 2 to 10,000 c.
5E Hydrophone: 100 to 40,000 c.

Designer: Bell Telephone Laboratories.

Manufacturer: Western Electric Company.

Reference: NDRC Report No. 6.1-sr346-1321, March 20, 1944.[31]

Description: Each of these hydrophones consists of a transducer unit and an associated two-tube preamplifier contained in a common housing. The 5C unit contains eight 45° X-cut Rochelle salt crystals connected in parallel; the 5E unit has sixteen 45° Y-cut Rochelle salt crystals. In both units the crystals are assembled between a diaphragm, which is exposed to the water, and a resonator. The 5C preamplifier is designed to operate with 600 ohms across the output terminals. The 5E preamplifier is designed to operate with 135 ohms across the output terminals. The maximum output voltage that this amplifier can deliver into 135 ohms without overloading is approximately 1 v at 4 kc, which corresponds to about 15,000 dynes per sq cm. (The maximum for the 5C is about 1 v at 2 c and 0.5 v at 10 c into 600 ohms, about 1,000 dynes per sq cm.) Housings for the two units are identical. Twenty-five feet of rubber-insulated cable is provided. Combined weight of hydrophone and cord: 12 lb

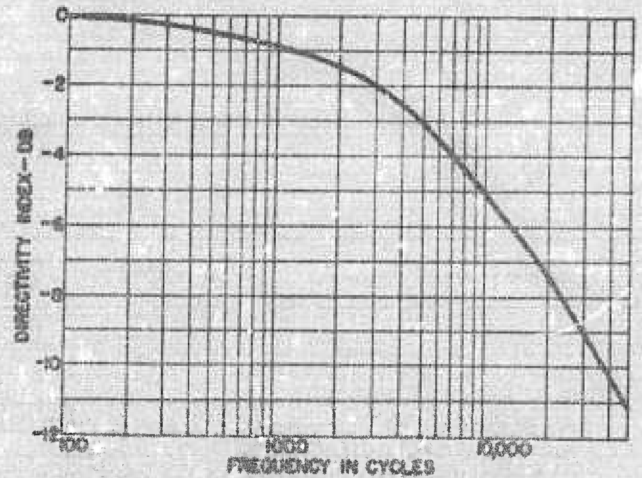


FIGURE 77. Directivity index, 5C and 5E hydrophones.

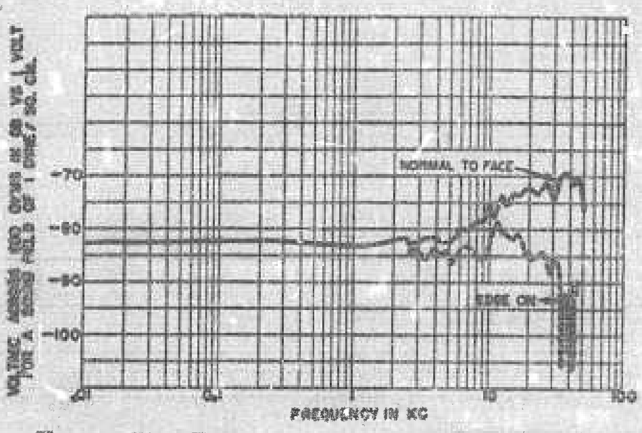


FIGURE 78. Receiving response, 5C hydrophone.

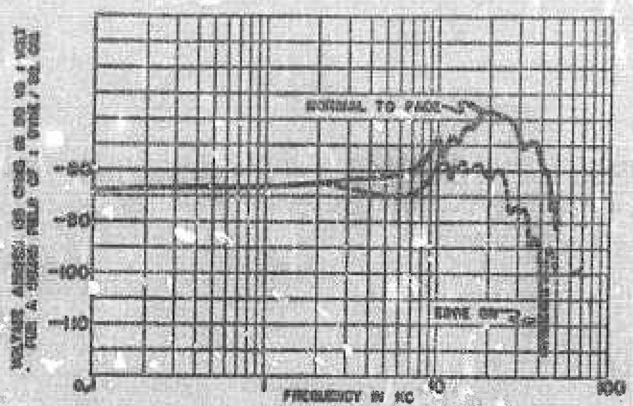


FIGURE 79. Receiving response, 5E hydrophone.

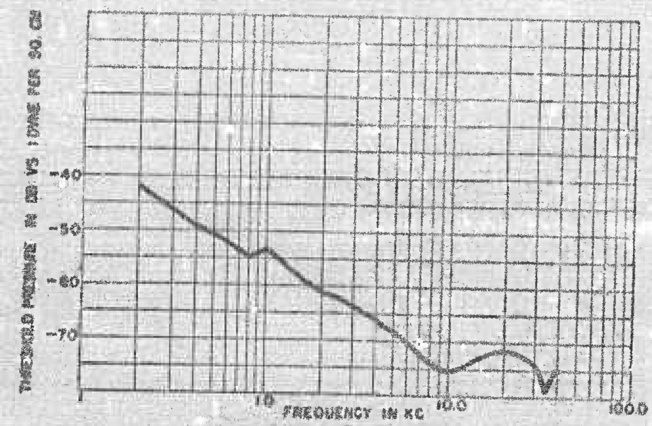


FIGURE 80. Measured threshold, 5E hydrophone.

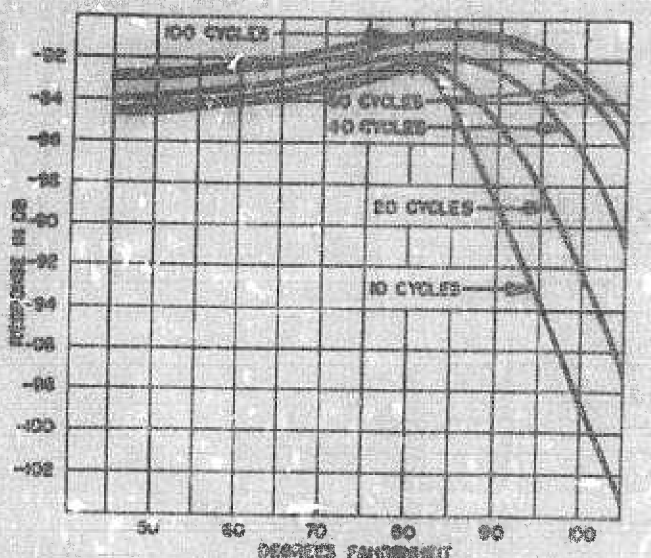


FIGURE 81. Effect of temperature on response of 5C hydrophone.

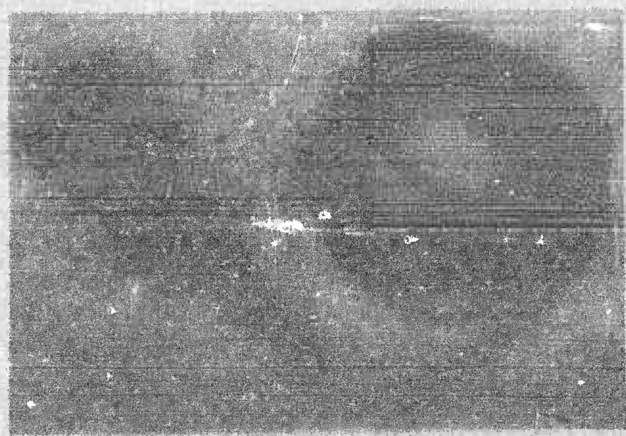


FIGURE 82. 5C or 5E hydrophone.

FIGURE 83. 5C or 5E hydrophone, interior view.

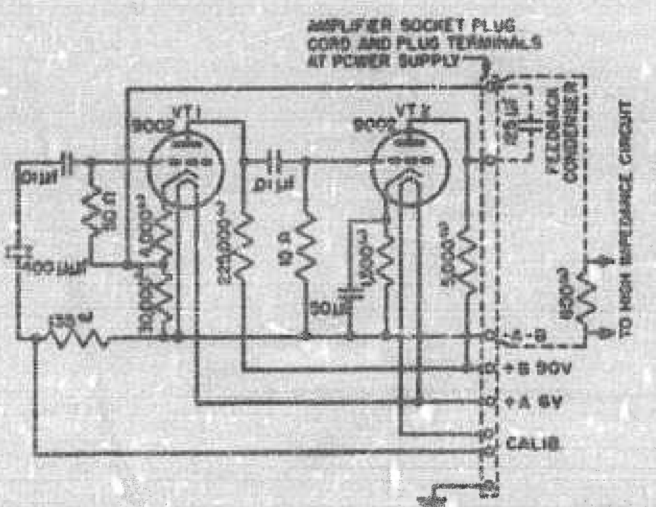


FIGURE 84. Circuit schematic, 5C hydrophone.

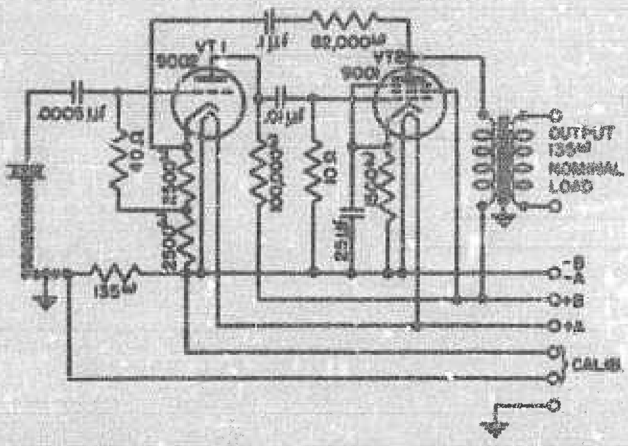


FIGURE 85. Circuit schematic, 5E hydrophone.

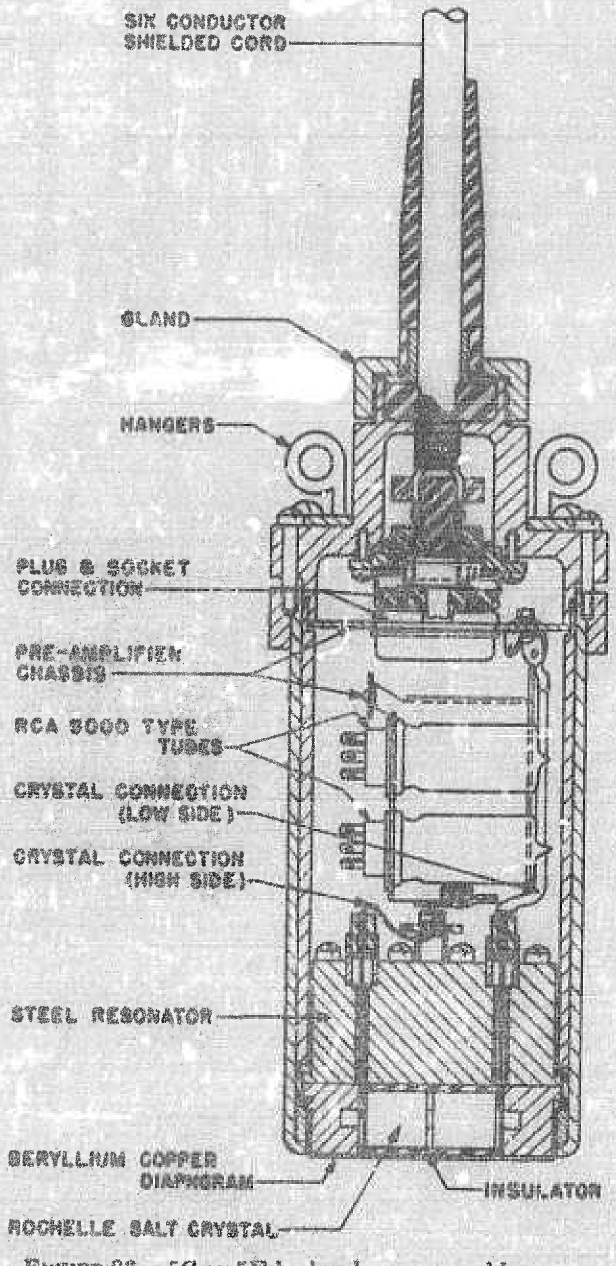


FIGURE 86. 5C or 5E hydrophone, assembly cross section.

1.4.17 C11-A1 Hydrophone

Type: X-Cut Rochelle Salt Crystal.

Operating range: 100 to 100,000 c.

Designer and Manufacturer: Brush Development Company.

References: Brush Report No. LR-47, March 4, 1942.[4]
NDRC Report No. C4-sr20-147, July 27, 1942.[7]
NDRC Report No. C4-sr20-148, July 27, 1942.[8]
NDRC Report No. 6.1-sr20-952, August 30, 1943.[203]

Description: The transducer element is a Rochelle salt crystal block, 5/16 in. square by 5/16 in. long, mounted in a brass ring. The 5/16-in. faces are covered by thin Phosphor bronze diaphragms, which are cemented to both the crystal faces and the ring housing. The surface of the crystal assembly is chrome-plated. A preamplifier is contained in a cylindrical, chrome-plated, brass housing, isolated mechanically from the crystal head by a rubber connection. The preamplifier overloads at approximately 50,000 dynes per sq cm. It is recommended that the resistance across the output terminals be 500 ohms. A 28-ft, 5-conductor, shielded cable is attached to the preamplifier housing.

Length: Approximately 9 13/16 in.

Weight: 2¼ lb.

Weight of cable: 4½ lb.

Directional characteristics: Output of microphone independent of angular position below 50,000 c.

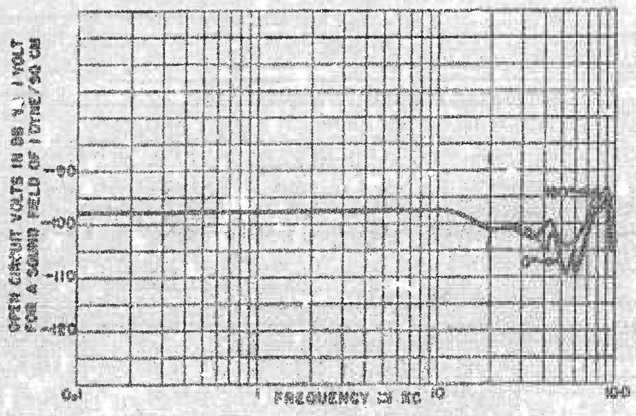


FIGURE 87. Receiving response, C11-A1 hydrophone.

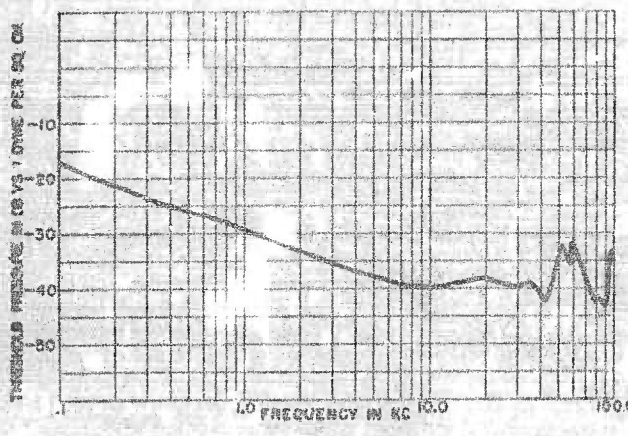


FIGURE 88. Measured threshold, C11-A1 hydrophone.

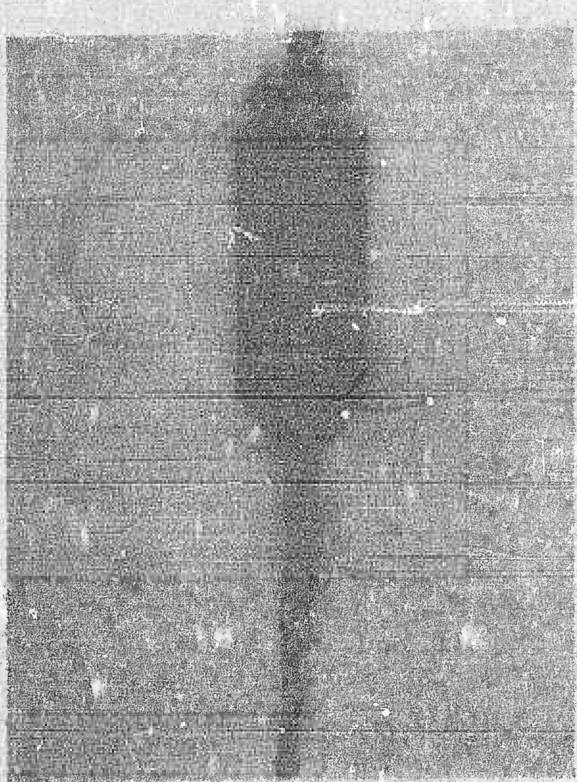


FIGURE 89. C11-A1 hydrophone.

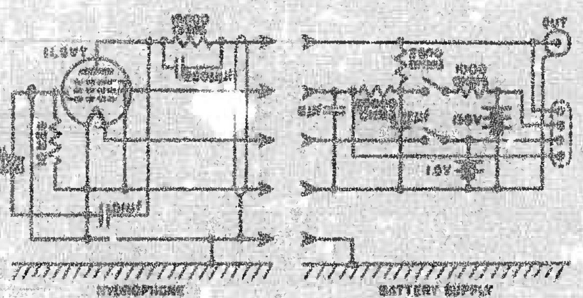


FIGURE 90. Preamplifier circuit, C11-A1 hydrophone.

1.4.18

Condenser Hydrophone (CMF)

Type: Condenser.
Operating range: 0 to 75 c.
Designer: Massachusetts Institute of Technology.
References: MIT Research Project D.I.C. 5935, Series A1, No. 12, April 1, 1943.[18]
NDRC Report No. 6.1-sr20-881, June 30, 1943.[29]

Description: The hydrophone is T-shaped and has two diaphragms located at the ends of the crossbar of the "T." The remainder of the housing contains a transformer and a pressure equalizing system which compensates for changes in static pressure. In this compensating system, water is led into a chamber surrounding an air-filled rubber bag. The pressure on the bag is transferred by means of air ducts to the back of the diaphragm. The hydrophone may be calibrated by lowering it to a known distance in water with the pressure equalization chamber closed.

The complete listening system includes, besides the hydrophone with its built-in transformer and cable, associated electrical equipment known as the *Bridge Modulator Model C* (BMC) assembly and mounted separately in a cabinet 2x19.5x14.5 in. This assembly consists of a Wien impedance bridge, oscillator, attenuator, band-pass amplifier, detector, and power supply.

Weight of hydrophone: About 16 lb.
Weight of BMC cabinet: About 75 lb.

Directional properties: Essentially nondirective.

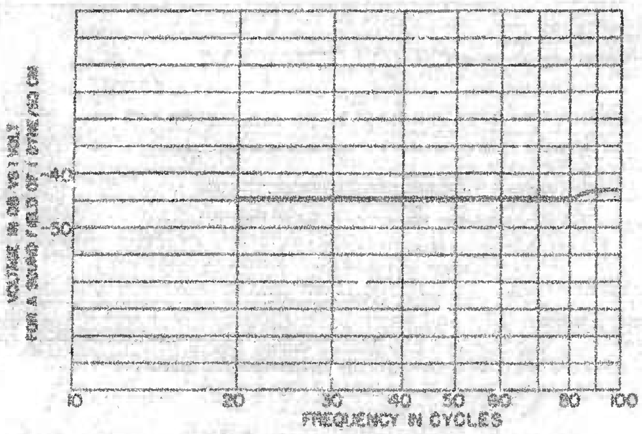


FIGURE 91. Receiving response, condenser hydrophone.

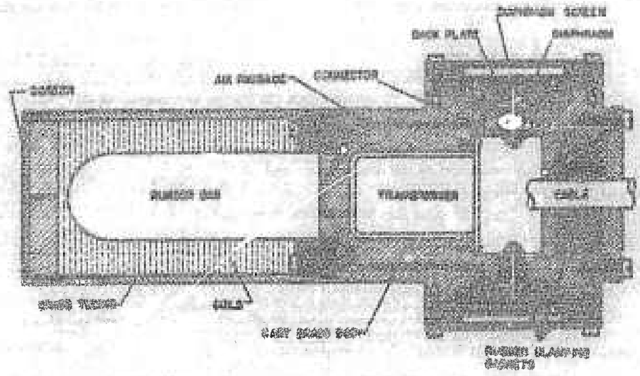


FIGURE 93. Condenser hydrophone, assembly cross section.

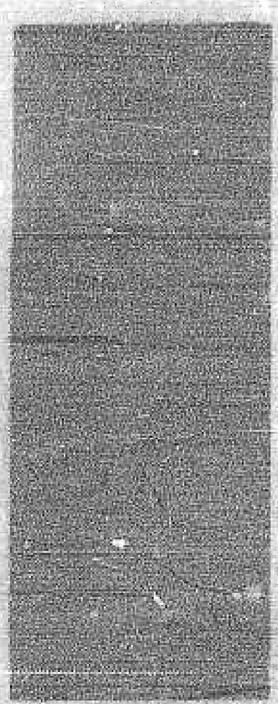


FIGURE 92. Condenser hydrophone.

1.4.19

HK Type Hydrophone

Type: X-Cut Rochelle Salt Crystal.

Operating range: 20 to 10,000 c, except HKB from 10 to 5,000 c and HKC from 2 to 5,000 c.

Designer: Massachusetts Institute of Technology.

References: MIT Research Project D.I.C. 5985, Series A1, No. 10, March 5, 1943.[17] No. 13, May 17, 1943.[20]
NDRC Report No. 6.1-sr20-879, June 19, 1943.[21]
NDRC Report No. 6.1-sr20-881, June 30, 1943.[23]

Description: The 45° X-cut Rochelle salt crystal head is contained in a cylindrical brass case about 2½ in. in diameter and 1½ in. thick. In the original assembly four crystal elements ¼x1x¾ in. were connected series parallel. Two metal diaphragms ⅛ in. thick covered the two ends of the crystals exposed to the water. The contact surfaces of the crystal and diaphragms were ground optically flat to insure contact over the whole area, with only a thin film of cement. Figure 96 shows a typical HK hydrophone.

Associated with the hydrophone is a single-stage preamplifier of the cathode-follower type mounted in a cylindrical housing about 1⅝ in. in diameter and 10 in. in length.

Modifications to reduce response variations with temperature were made. In particular, a rubber diaphragm was substituted for the metal diaphragm in the HKB and HKC models.

In order to extend the low-frequency range, the connection of crystals was changed from series parallel to parallel, thus lowering the impedance of the crystal head. In the HKC hydrophone, in addition, the crystal block was divided into eight crystals to further lower the impedance. These changes and accompanying improvements in the preamplifier design culminated in the HKC hydrophone which has a uniform response down to 2 c.

TABLE 1. Comparison of HK type hydrophones.

Hydrophone model	Diaphragm	Crystal connections	Response (db)*	Low-frequency droop 250–20 c (db)	Temperature dependence† (db)		Useful range (c)
					20 c	250 c	
HK	Brass	4 in series parallel	−85	6–10	11	8	20–10,0
HKA	Brass	4 in parallel	−90	2–4	6	4	20–10,0
HKB	Rubber	4 in parallel	−90	0	3	2	5–5,00
HKC	Rubber	8 in parallel	−95	0	1.5	1.5	2–5,00

* Approximate response at output of preamplifier.
† The temperature dependence is measured by the maximum change in response from 0 C to 23.8 C.

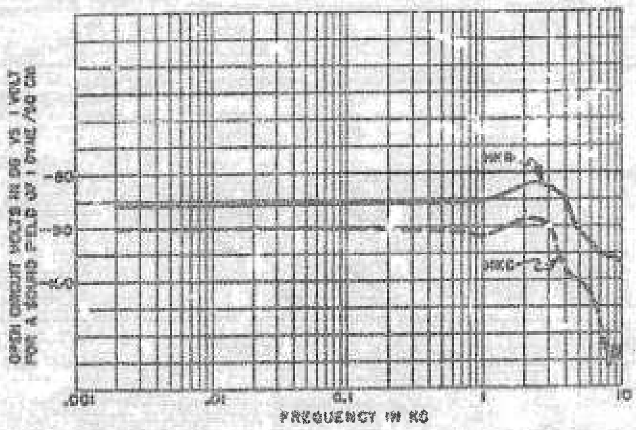


FIGURE 94. Receiving response, HKB and HKC hydrophones.

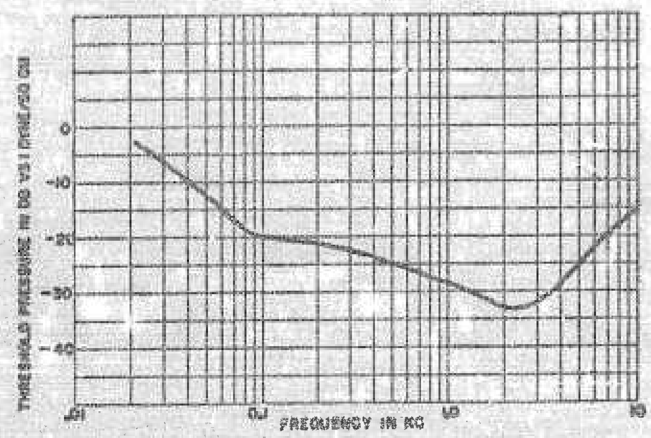


FIGURE 95. Measured threshold, HKB hydrophone.

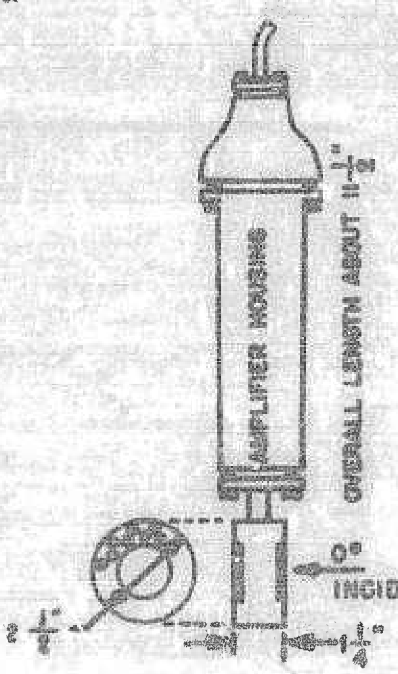


FIGURE 96. HK hydrophone.

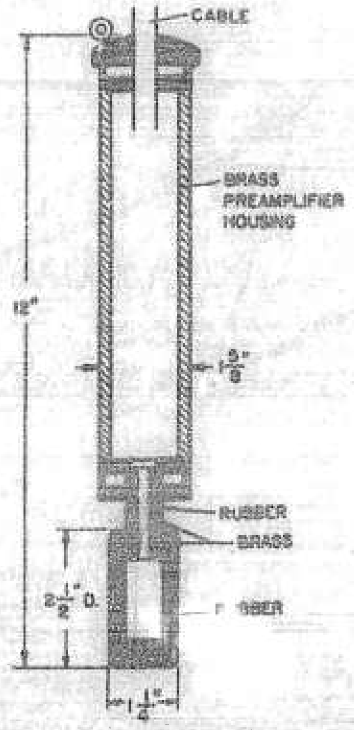
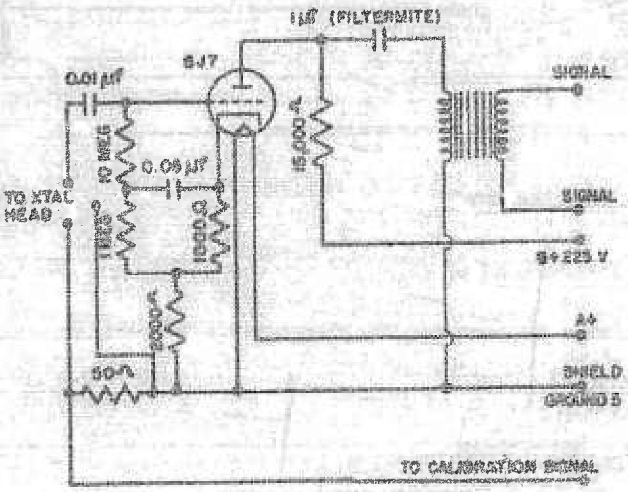


FIGURE 97. HKB hydrophone, assembly cross section.



NOTE: CIRCUIT CAN BE MODIFIED TO EXTEND LOW FREQUENCY RANGE. OUTPUT TRANSFORMER IS THEN OMITTED.

FIGURE 98. Preamplifier circuit, HKB hydrophone.

1.4.30

OLA Hydrophone

Type: Tourmaline Crystal.

Operating range: 8 to 90 kc.

Designer: Naval Research Laboratory.

References: NDRC Report No. 6.1-sr20-884, June 28, 1943.[22]
NDRC Report No. 6.1-sr1130-2132, January 31, 1945.[75]

Description: Four tourmaline disks, each ⅛ in. in thickness and $2\frac{3}{16}$ in. in diameter are cemented together and connected electrically in parallel. This stack is backed by a steel plate and a cork sheet. The assembly is supported in a spherical steel shell having a sound-transparent rubber window and mounted in a cast-bronze housing. The hydrophone is filled with castor oil. A 20-ft cable is part of the instrument.

Weight: Approximately 20 lb.

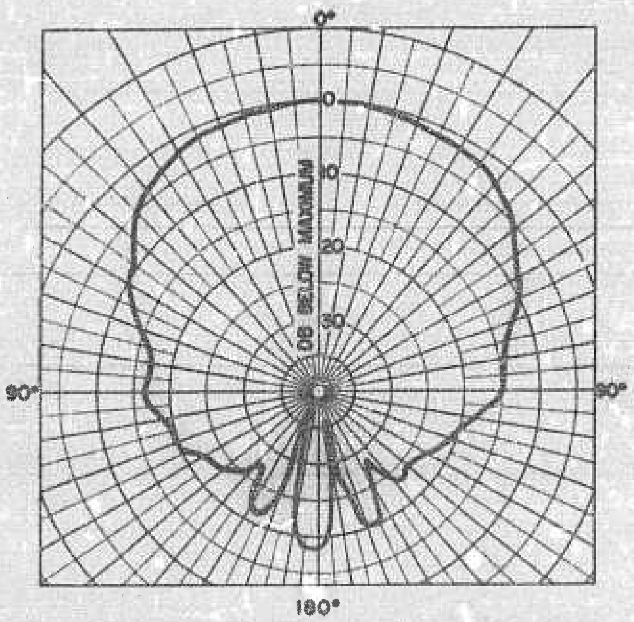


Figure 99. Directivity pattern, OLA hydrophone at 25 kc.

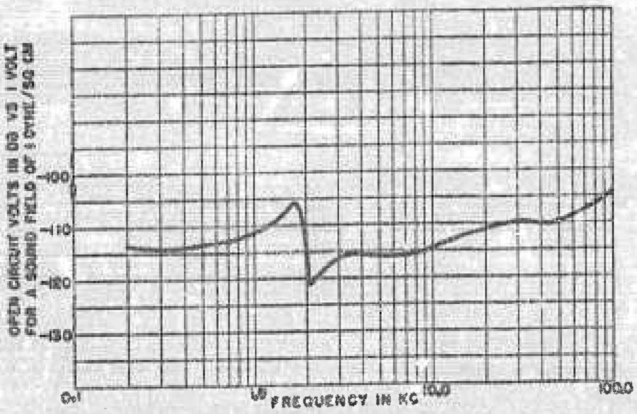


Figure 100. Receiving response, OLA hydrophone.

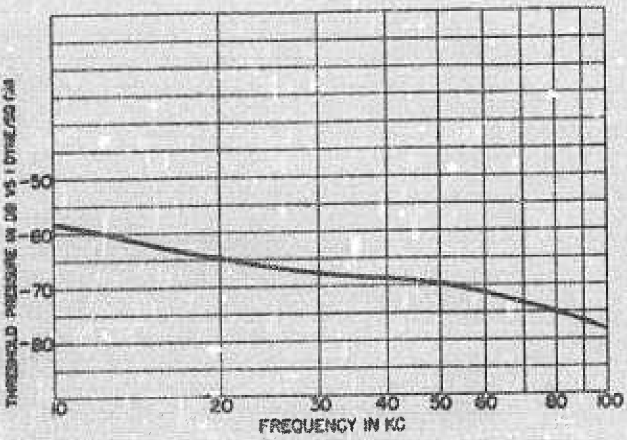


Figure 101. Calculated threshold, OLA hydrophone.

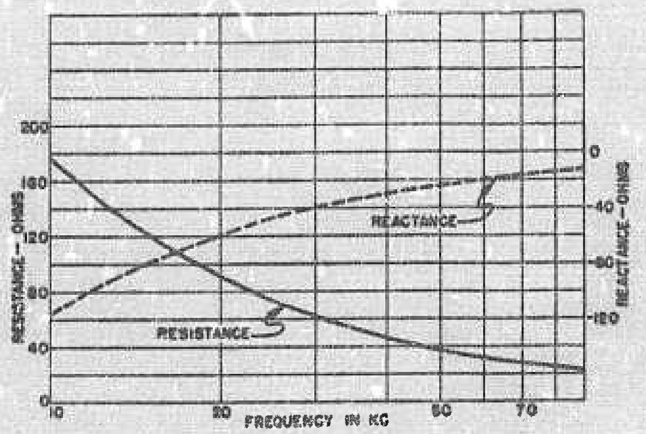


Figure 102. Impedance, OLA hydrophone.

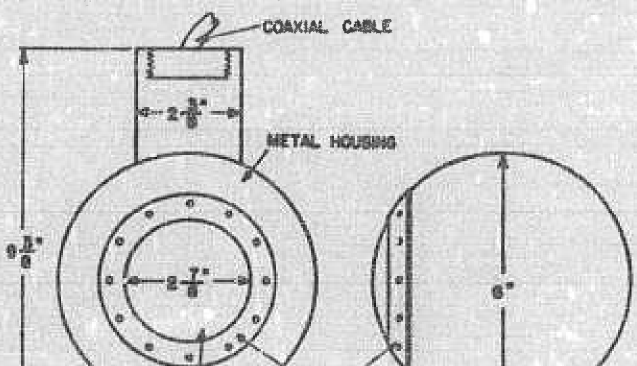


Figure 103. OLA hydrophone.

1.4.21 **XMX Hydrophone**

Type: X-Cut Rochelle Salt Crystal.

Operating range: 300 c to 2,000 kc.

Designer: Underwater Sound Laboratory, Massachusetts Institute of Technology.

Reference: NDRC Report No. 6.1-sr1130-1685, July 11, 1944.[34]

Description: The crystal head, composed of four 45° X-cut Rochelle salt crystals, has dimensions ¼x¼x⅜ in. The assembly is housed in a rectangular bakelite holder protected by two layers of neoprene. A 5-in. cable connects the crystal holder to the cylindrical preamplifier housing. The preamplifier is designed to handle, without overloading, output voltages up to about 7 v corresponding to an applied sound pressure of approximately 400,000 dynes per sq cm. Because of its broad frequency response, the instrument has been widely used for the measurement of aperiodic sounds.

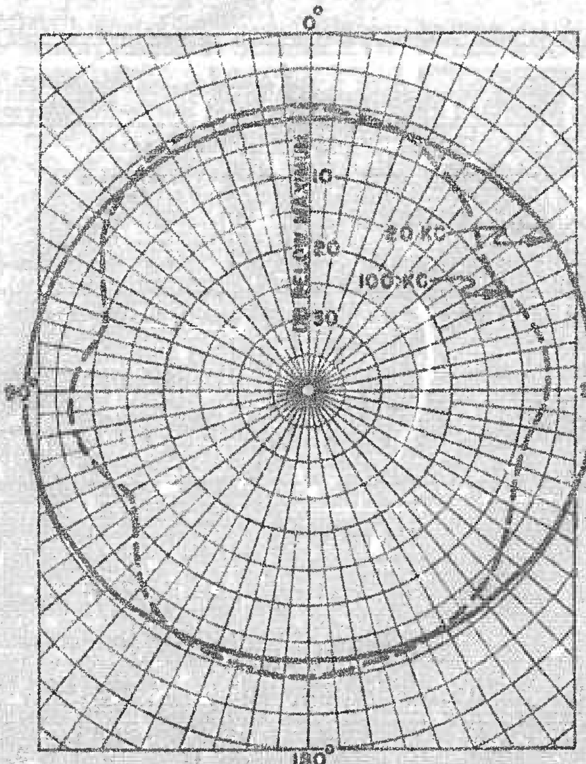


FIGURE 104. Directivity patterns, XMX hydrophone in a plane perpendicular to the axis.

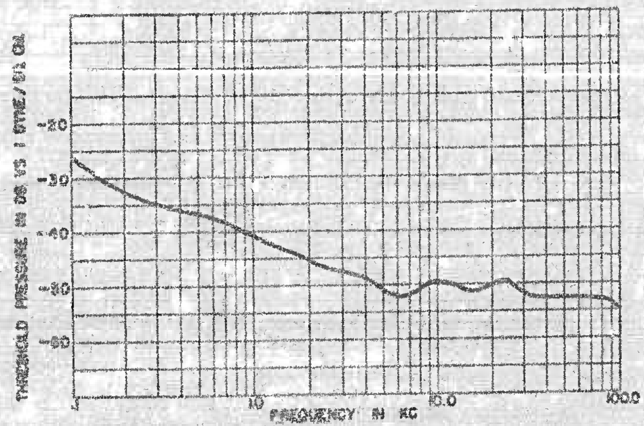


FIGURE 106. Measured threshold, XMX hydrophone.

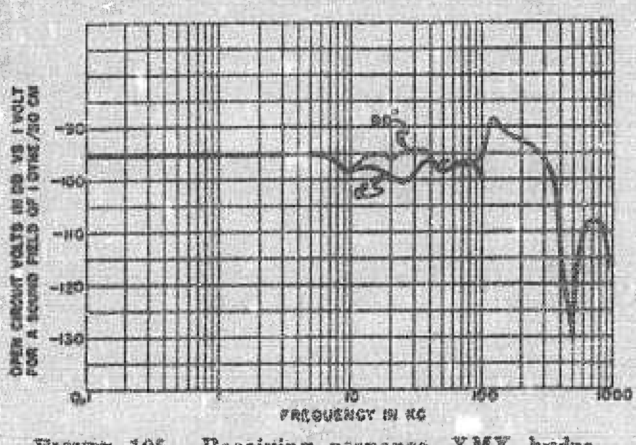


FIGURE 105. Receiving response, XMX hydrophone.

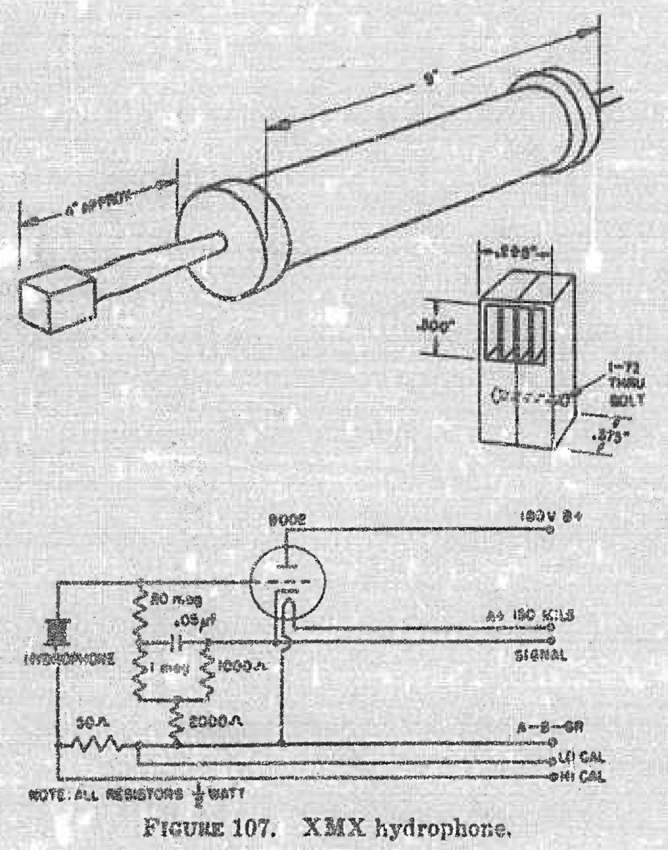


FIGURE 107. XMX hydrophone.

Chapter 2

U. S. NAVY SONAR EQUIPMENTS

2.1 INTRODUCTION

Sonar equipments are the underwater eyes and ears of U. S. Navy vessels. By their use the range and bearing of other vessels or of submerged objects can be determined. The presence and bearing of moving vessels or other noise sources can be detected. Some equipments scan the ocean bottom and tell the depth of the water beneath the vessel. If so desired, these equipments will chart the contour of the bottom over which the vessel passes. Sonar equipments also permit underwater telegraphic communication between vessels similarly equipped.

For security reasons supersonic frequencies (15 to 30 kc), rather than frequencies in the sonic range, are used for ranging, sounding, and telegraphing. A more directive projector beam pattern is obtainable at the higher frequencies. Listening equipments are designed for use in both the sonic and the supersonic frequency range.

The physical characteristics of the underwater sound devices which affect the operational performance of sonar equipments have been outlined.[133] These pertinent characteristics are determined for any sonar equipment almost wholly by the transducer or projector, the associated electronic circuit being of lesser importance. Accordingly, the USRL calibrations of sonar equipments are usually confined to projectors and include other apparatus only when special functions are involved.

The quartz sandwich type "oscillator" was one of the first projectors used in Great Britain for echo ranging. In this country the 19-in. spherical magnetostriction-type projector was developed. This projector has the advantage of simplicity and ruggedness. Rochelle salt crystal (JK) units were used for listening. These units were in many cases combined with the magnetostriction (QC) unit in the same spherical housing.

The spherical projector, which is used without a dome, cannot be operated at ship speeds greater than about 15 knots because of excessive noise produced by cavitation of the surrounding water. Ethylene glycol solution is used as an antifreeze liquid in this projector. Since this liquid causes considerable transmission loss,[63] present practice in sonar equipment design is to place the projectors inside free-flooding streamlined domes, which have a higher cavitation point. Domes have now been designed which have low transmission losses and do not seriously affect the projector beam patterns. The more recent projectors are, as a result, designed for maximum efficiency and optimum performance characteristics without regard to shape.

The original JK-type projectors are made with X-cut Rochelle salt crystals. Although these projectors are efficient over a wide frequency range, they are subject to variations with temperature and are limited in the amount of power they will handle.[69] For these reasons, their use has been restricted mainly to listening systems. Recent advances in the design of projectors using ammonium dihydrogen phosphate [ADP] crystals now make them suitable for use as echo-ranging transducers. This is made possible by the temperature independence and higher load carrying capacity of the ADP crystal.

Model letters are used generally to identify sonar equipments with regard to basic differences and purposes of the systems. The equipments now in service include the following:[a]

Listening equipments—J series.

- JK. Used in conjunction with QC ranging.
- JN. Small portable, nondirectional.
- JO and JQ. Use parabolic hydrophones; limited number only.
- JP. Uses toroidal M/S hydrophone; JP-1 uses line M/S hydrophone.
- JT. Improved JP system, uses 5-ft M/S line hydrophone.

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[a] In this volume, M/S is the abbreviation for magnetostriction and R/S for Rochelle salt.

Echo-sounding equipments—N series.
- NJ. Range 200 fathoms, separate M/S projectors for transmitting and receiving, condenser-discharge type driver.
- NK. Range 200 fathoms, two M/S projectors in streamlined housing, condenser-discharge type driver.
- NM. Heavy-duty M/S type, range up to 2,000 fathoms.

Echo-ranging equipments—Q series.
- QB. R/S or ADP crystal projector, heavy-duty type.
- QC. M/S projector, heavy-duty type.
- QG. M/S projector, incorporates all latest improvements.
- QJ. R/S or ADP projector, incorporates all latest improvements.

Combination ranging, listening, and sounding—W series.
- WA. M/S projectors.
- WB. R/S or ADP projectors.
- WC. M/S and R/S projectors, M/S sounding.
- WD. M/S and R/S or ADP projectors, R/S sounding.
- WE. M/S projectors, lightweight.

The major units in sonar equipments are identified by letters and numbers, for example CBM 78138. The letters designate the manufacturer (CBM = Submarine Signal Company) and the first two numerals the type of equipment. The last three numerals are assigned in the order the requests are received.[b]

2.2 LISTENING EQUIPMENTS—J SERIES

The original J-series listening equipments were designed for use on submarines.[66] The scope of this series has been extended to cover equipments for use on small-type picket boats, patrol craft, Coast Guard Reserve vessels, etc. Listening equipments passed through development stages from straight stethoscope tubes to the modern equipments consisting of transducers, electronic amplifiers, and reproducing apparatus such as recorders, loudspeakers, and headphones. The useful listening range has been extended to cover supersonic frequencies up to about 50 kc. Later type equipments are provided with indicating devices which show right or left deviation of the bearing of the transducer relative to the true bearing of the source producing the noise. These indicating devices are of various types, including *bearing deviation indicator* [BDI] circuits similar to those used in echo ranging, *phase actuated locator* [PAL] systems for use on patrol craft, and *right-left indicator* [RLI] circuits which are used in the JT and WFA systems for submarines.[c]

Calibrations of transducers used in some of the listening equipments for U. S. Navy vessels, and, in some cases, associated apparatus also, have been made by the USRL. References to these calibrations are contained in Sections 2.7.1 to 2.7.6.

2.3 ECHO-SOUNDING EQUIPMENTS—N SERIES

The function of echo-sounding equipments is to measure the depth of water. This is done by transmitting a pulse of supersonic energy and noting the time required for the echo to return from the bottom of the ocean or from a submerged object as shown in Figure 1. Assuming the velocity of sound in water to be always the same, depth indicators can be calibrated directly in fathoms (1 fathom = 6 ft). The calibrations are usually based on a sound velocity of 4,800 fps.

The pulse is transmitted by a projector mounted in the hull of the ship near the keel line. The projector normally is mounted flush with the outer surface of the hull, facing downward. The echo is received by the same pro-

[b] Complete listings are given in *Model Letters and Type Numbers, Assignment to Naval Radio and Sound Equipment* (RE 15A 101J).

[c] All the indicating circuits are based on the difference in arrival time of sound at the two halves of a split hydrophone. In the BDI-type circuit the signals from the two halves of the hydrophone are combined so as to produce on the screen of a cathode-ray oscilloscope a right or left deflection of the electron beam corresponding to the deviation of the true bearing of the target from the training angle of the hydrophone. In the PAL and RLI circuits the deviation is indicated by positive or negative current readings on a zero-center microammeter.

jector or, in some cases, by a second projector similarly mounted and adjacent to the trans-

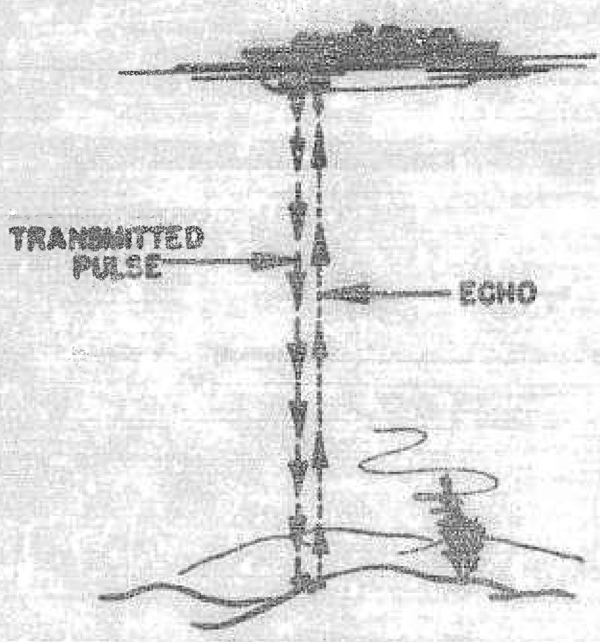


FIGURE 1. Sound transmission path in echo sounding.

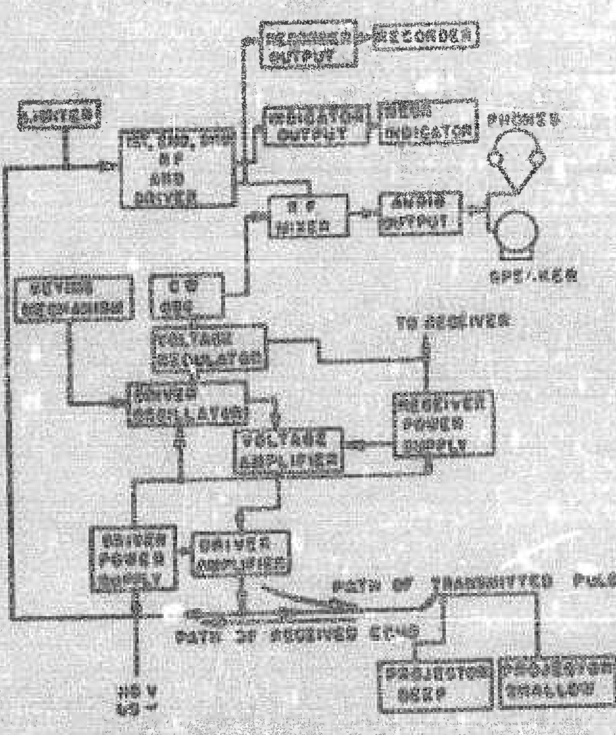


FIGURE 2. Block diagram, NMC sounding equipment.

mitting projector. In most sounding equipments the acoustic pulse consists of a short train of waves at a supersonic frequency (generally 18, 20, or 24 kc). In some equipments, for example, the NJ type, the pulse consists of a damped sinusoidal wave obtained by shock-exciting the transmitting projector by means of a condenser discharge.

The received echo is indicated in three ways: (1) as an audio-frequency signal which is fed into a loudspeaker, (2) as a radio-frequency signal which energizes a neon lamp indicator, (3) as voltage to a recorder stylus needle. The first method allows aural monitoring. The second method provides a visual indication of the depth in fathoms through an aperture in a moving belt traveling behind a linear scale calibrated in fathoms. The third method permits a trace to be made on calibrated recorder paper corresponding to the depths encountered

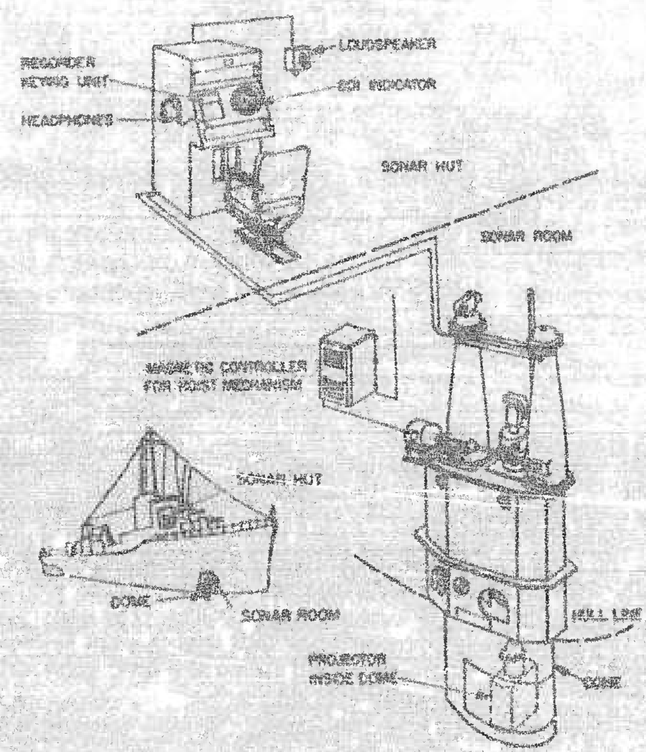


FIGURE 3. Outline of QJA equipment in ship.

over a period of time. By this last means a permanent record of the contour of the ocean bottom is made. A block diagram of the NMC equipment, which is typical of sounding equipments in general, is shown in Figure 2. Reference to calibrations are contained in Sections 2.7.7 to 2.7.14.

3.4 ECHO-RANGING EQUIPMENTS—Q SERIES

Echo-ranging equipments are used to obtain the range and bearing of surface and underwater vessels, reefs, buoys, etc. This is done by projecting a pulse of supersonic energy into the water and noting the time required for energy reflected from the distant object to return as an echo and the direction from which such an echo arrives.

The acoustic pulse, which generally is at a frequency in the range from 14 to 30 kc, is

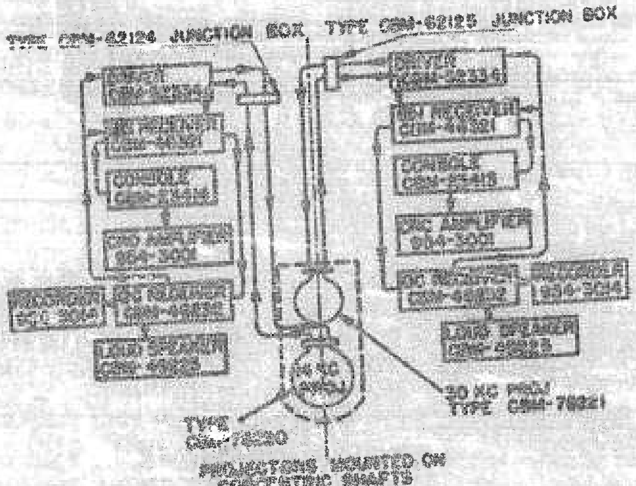


Figure 4. Functional block diagram, QGA equipment.

generated by a projector extending from the hull of the vessel. (In some equipments for small boats the projector is put into the water over the side of the boat.) Except for the spherical-type projectors and a few streamlined types, the projector generally is housed inside a streamlined dome. The QJA dome shown in Figure 3 can be extended when in working position and retracted inside a sea chest at other times. Some domes are nonretractable, that is, they are welded to the hull, or "fixed."

The projector which transmits the pulse is, as a rule, also used to receive the echo. The received signal is indicated in several ways. (1) It is converted to an audible frequency for aural monitoring on headphones or loudspeaker. (2) The echo is converted to a voltage which flashes a neon light traveling over a linear scale calibrated directly in yards. This provides a visual indication of the range. (3) The received signal is amplified and rectified to produce a voltage which is impressed on the stylus

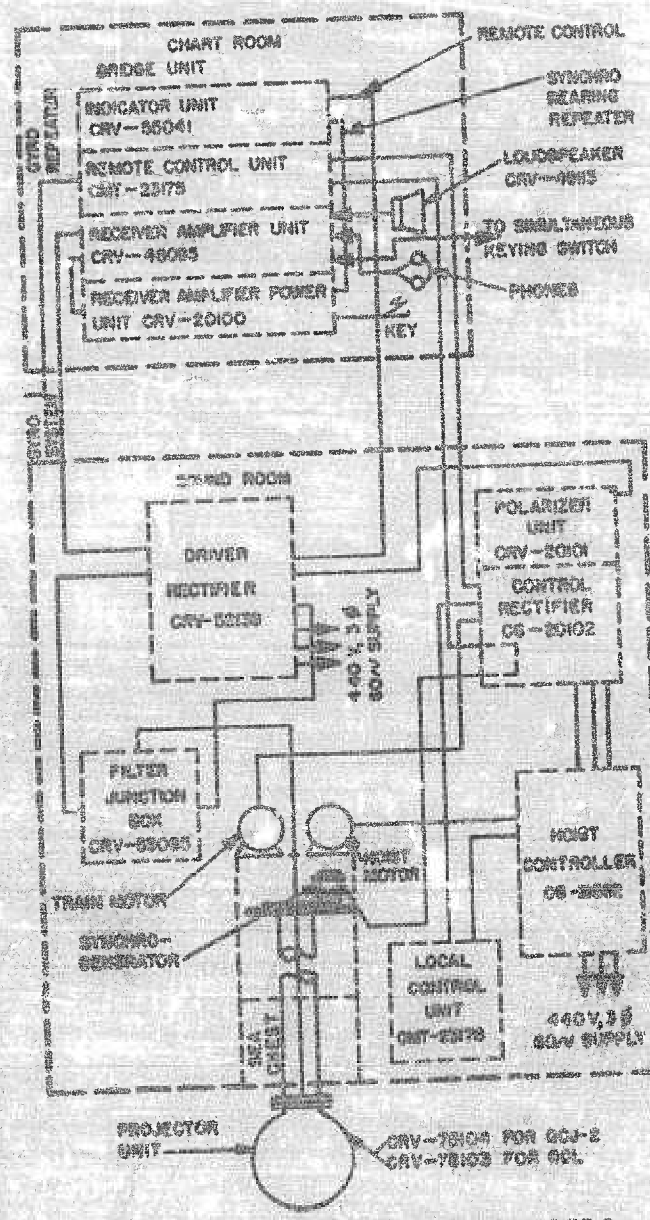


Figure 5. Functional block diagram, QCJ-2 or QCL equipment.

of a chemical recorder unit. The stylus of this unit is caused to travel at constant speed over a chemically sensitized paper. A mark is made on the paper when the d-c signal voltage is impressed on the stylus and a calibrated scale is used to translate the trace made by the stylus on the paper to target range in yards. (4) A

BDI unit is included in many of the systems. This permits visual indication on a cathode-ray oscilloscope screen of whether the projector is trained directly on, or to the right or to the left of, the target. When BDI is not used (QC reception), the bearing is determined by intensity of the received echo.

Echo-ranging equipments usually are adapted for listening in the supersonic frequency range to sounds caused by the propellers or other moving machinery in vessels, or listening to other underwater noise. Usually such equipments are arranged for telegraphic communication with other vessels similarly equipped.

A functional block diagram of the QGA equipment is shown in Figure 4 and of the QCJ-2 or QCL equipment in Figure 5. These are typical of echo-ranging systems in general use. References to calibrations are contained in Sections 2.7.15 to 2.7.33.

2.5 SONAR-RANGING EQUIPMENT—W SERIES

All W-series equipments are combinations of systems for ranging, listening, and sounding. In some WEA, WEA-1, and WEA-2 equipments, the 45° inclined baffles installed in the domes for use in sounding were found to be unsatisfactory and were removed so that these equipments could no longer be used for echo sounding. All other W-series equipments, however, contain the three features outlined. References to calibrations are contained in Sections 2.7.34 to 2.7.38.

2.6 EXPERIMENTAL PROJECTORS

A number of experimental type projectors were tested by the USRL. While these instruments were designed primarily for application in sonar equipments, their present status is somewhat uncertain. The characteristics of any particular one of these instruments may not be representative of the eventual product of the group. The calibrations of these units, however, are of particular interest because of the many novel features incorporated in their design. References to these calibrations are contained in Sections 2.7.39 to 2.7.49.

2.7 SONAR EQUIPMENTS

2.7.1 JK Sonar-Listening Equipments

Type: X-Cut Rochelle Salt Crystal.

Manufacturer: Submarine Signal Company and Radio Corporation of America.

Description: The JK-type equipment is usually used in conjunction with QC-type gear. The transducers are Rochelle salt crystal types. The JK-type transducers in this report are covered under echo-ranging projectors, as the JK crystal unit is usually combined in one housing with a magnetostriction (QC) echo-ranging projector, or is used as the transducer in echo-ranging systems in addition to serving as the hydrophone in the listening equipment.

2.7.2 JO Parabolic Hydrophone Assembly (CBD 51035)

Type: X-Cut Rochelle Salt Crystal.

Designer and Manufacturer: Brush Development Company, Type No. C35.

Reference: NDRC Report No. C4-sr20-280, September 23, 1942.[15]

Application: The CBD 51035 is a major unit in the JO listening equipment for picket boats. The assembly is mounted on the outer surface of the hull as a blister-like attachment. Only a limited number of the JO equipments are in service.

Description: The CBD 51035 hydrophone assembly consists of two C36-type hydrophones mounted in a rubber-covered blister. The C36 hydrophone consists of a block of X-cut Rochelle salt crystals mounted in the focal plane of a parabolic reflector. The blister is formed of ¾-in. black rubber with a circular window of sound-transparent rubber over the mouth of each reflector.

Impedance of C36 Hydrophone

At 1 kc = 11 − j45 ohms

At 5 kc = 5 − j3.5 ohms

At 10 kc = 7.5 − j14 ohms

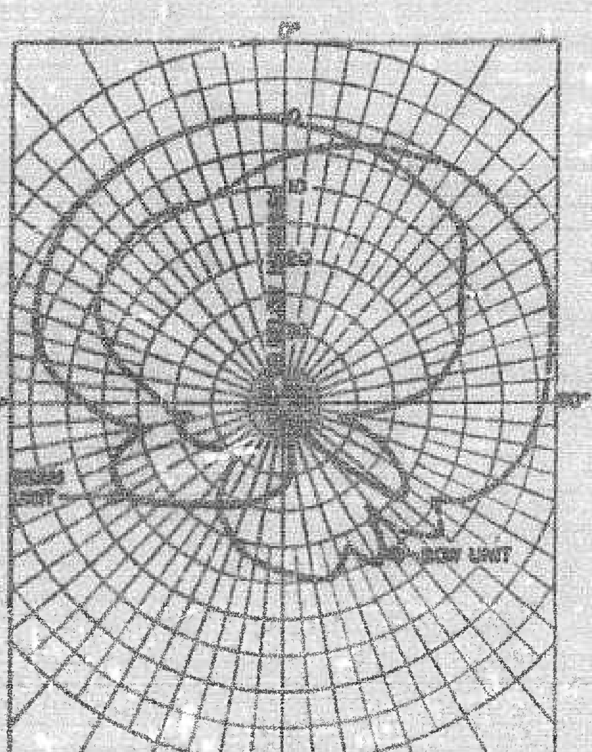


FIGURE 6. Directivity pattern, CBD 51035 assembly at 2 kc.

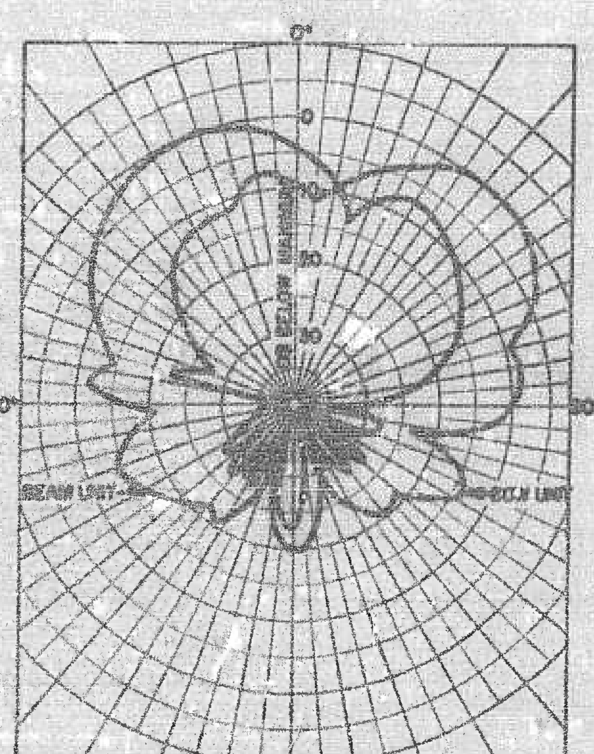


FIGURE 7. Directivity pattern, CBD 51035 assembly at 5 kc.

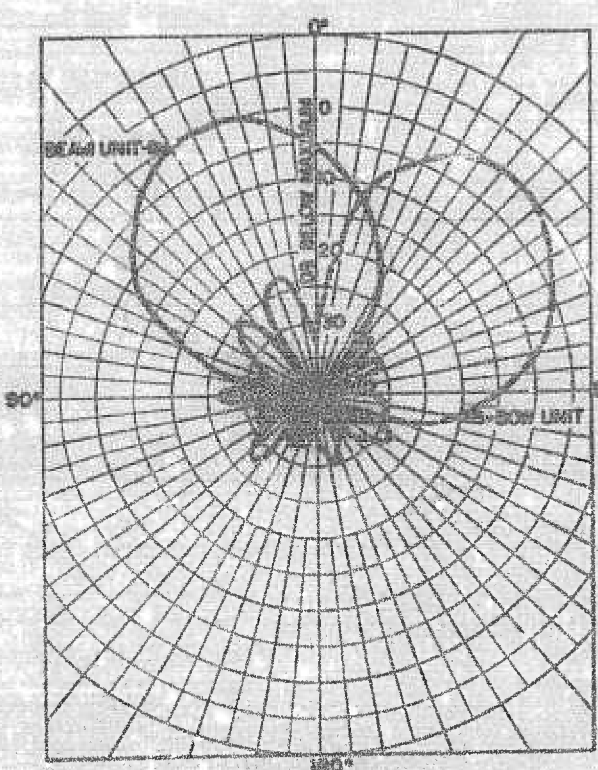


FIGURE 8. Directivity pattern, CBD 51035 assembly at 9.5 kc.

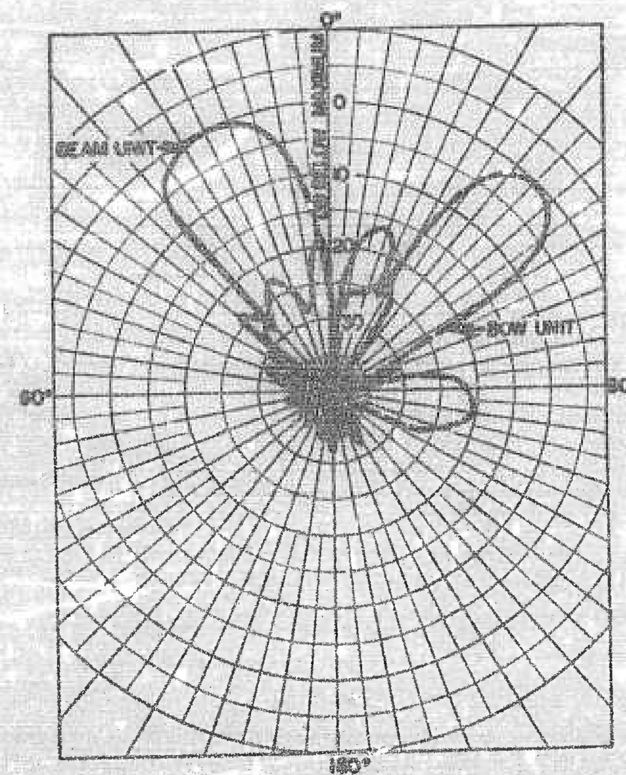


FIGURE 9. Directivity pattern, CBD 51035 assembly at 18.5 kc.

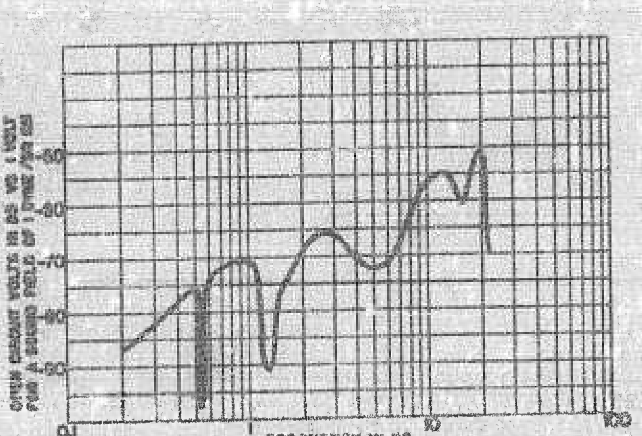


FIGURE 10. Receiving response, C36 hydrophone at output of UTC 65856 transformer (approximately 40 db voltage gain). Water temperature = 74 F. Calculated threshold at 5 kc = approximately −76 db vs 1 dyne/sq cm.

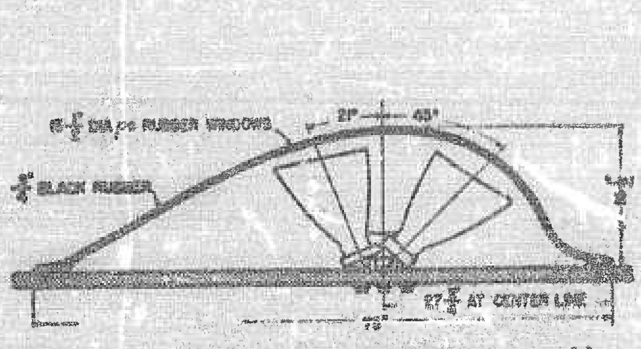


FIGURE 11. JO parabolic hydrophone assembly, CBD 51035.

2.7.3 JP Sonar-Listening Equipment

Type: Magnetostriction.

Designer: Columbia University, Division of War Research, at the U. S. Navy Underwater Sound Laboratory, New London, Conn. [CUDWR-NLL]

Description: Several versions of the JP equipment for submarines are in service:

1. JP. The JP, as originally designed, used a toroidal magnetostrictive-type hydrophone and was intended for use on slow-moving district craft, Coast Guard Reserve vessels, etc. Calibrations of the toroidal hydrophones are given in Sections 6.6.1 to 6.6.6.

2. JP-1. The JP-1 equipment makes use of a 4-ft line M/S hydrophone COG 51053 with a baffle to reduce rear response. USRL calibrations of the COG 51053 unit are given in Section 6.6.2.

2.7.4 JQ Sonar-Listening Hydrophone (CBD 51052)

Type: X-Cut Rochelle Salt Crystal.

Designer and Manufacturer: Brush Development Company.

Reference: NDRC Report No. 6.1-sr1130-1190, December 14, 1943.[60]

Application: The CBD 51052 hydrophone was designed for use in the JQ listening equipment for Coast Guard Reserve vessels and picket boats. Only a limited number of sets have been placed in service.

Description: The CBD 51052 hydrophone consists of a Rochelle salt crystal unit in a parabolic reflector. The unit is located at the approximate focal point of the reflector. The crystal unit is connected to the output terminals through a step-down transformer. The assembly of the Rochelle salt crystal, reflector, and coupling transformer is contained in a Corprene and rubber-covered metal housing. Holes through the housing permit the reflector to be free-flooded.

No impedance measurements on this device were made by USRL.

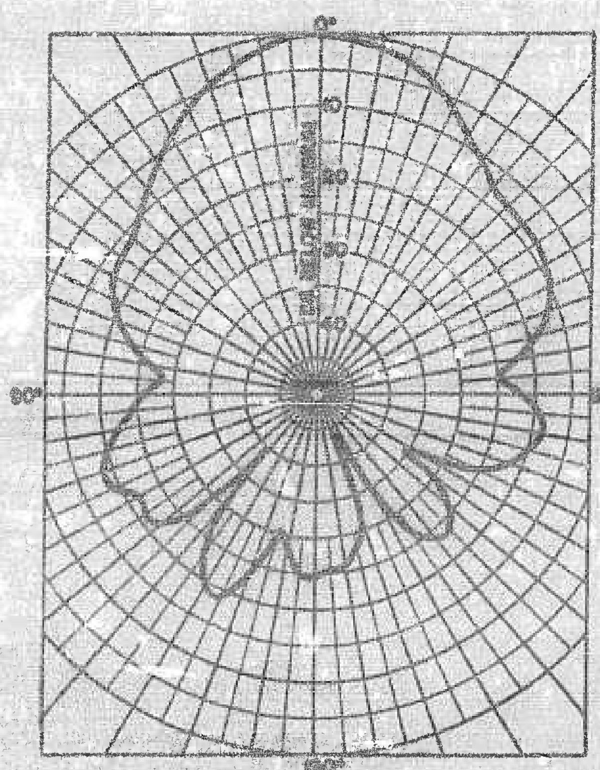


FIGURE 12. Directivity pattern, JQ hydrophone CBD 51052 at 8 kc.

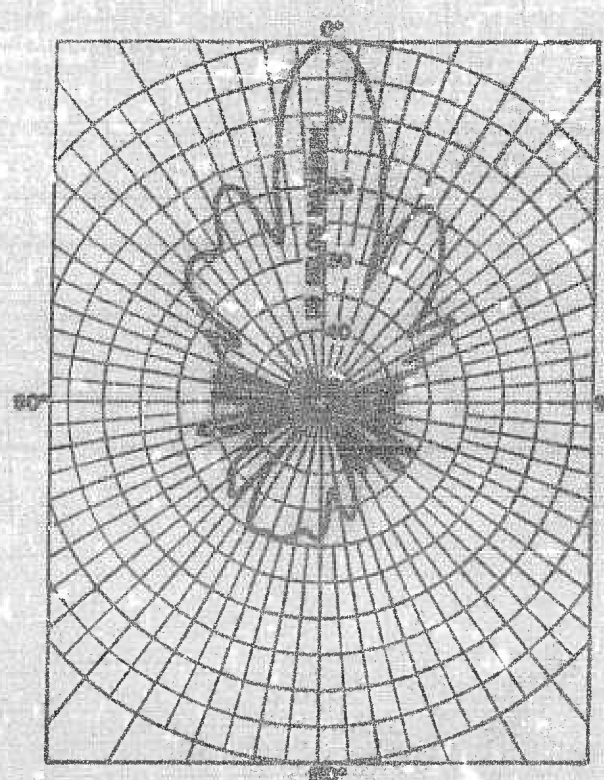


FIGURE 13. Directivity pattern, JQ hydrophone CBD 51052 at 24 kc.

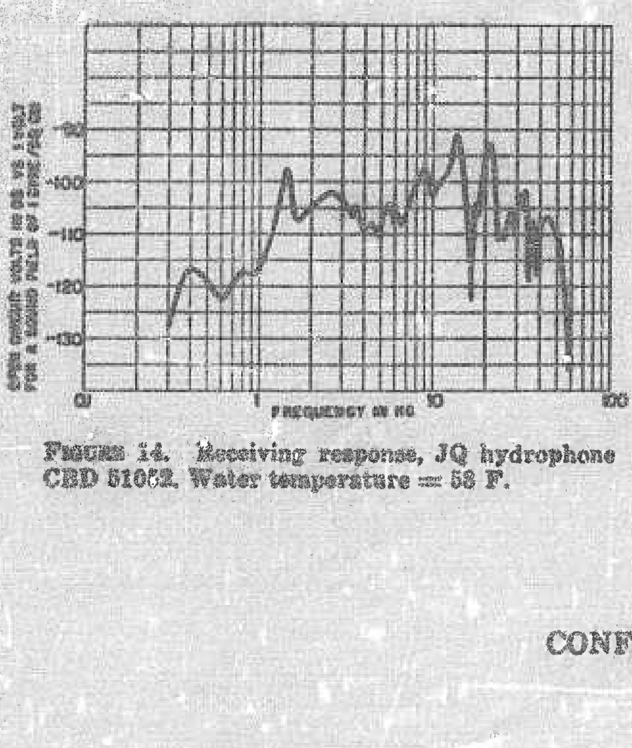


FIGURE 14. Receiving response, JQ hydrophone CBD 51052. Water temperature = 58 F.

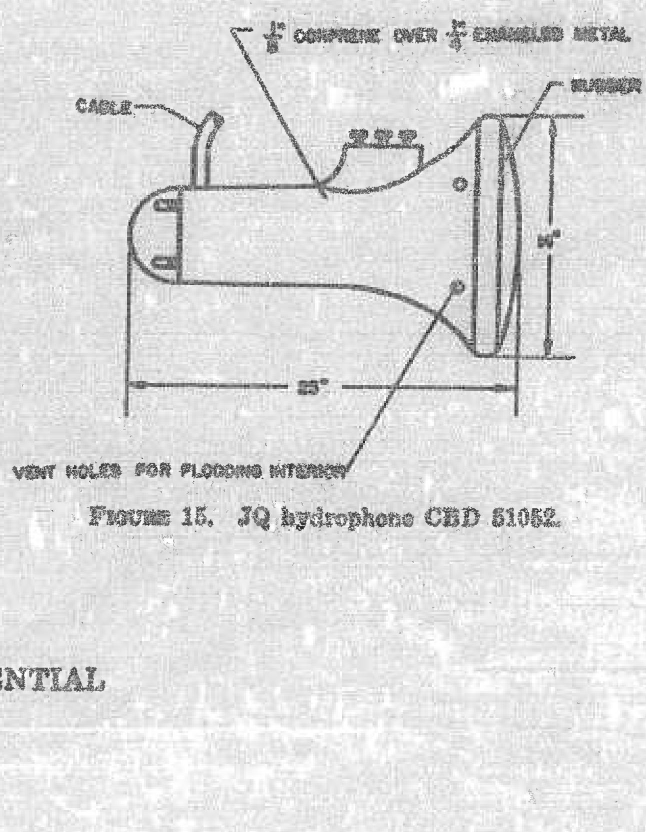


FIGURE 15. JQ hydrophone CBD 51052.

2.7.5 Modified JQ Sonar-Listening Hydrophone (CBD 51052)

Type: ADP Crystal.

Designer and Manufacturer: Brush Development Company.

Reference: NDRC Report No. 6.1-sr1130-1190, December 14, 1943.[60]

Application: This modified CBD 51052 unit is for use in the JQ listening system, replacing the Rochelle salt type unit.

Description: This hydrophone consists of an ADP crystal unit located at the approximate focal point of a parabolic reflector. A preamplifier couples the crystal unit to the hydrophone output terminals. This preamplifier is included in these calibrations.

No impedance measurements on this device were made by USRL.

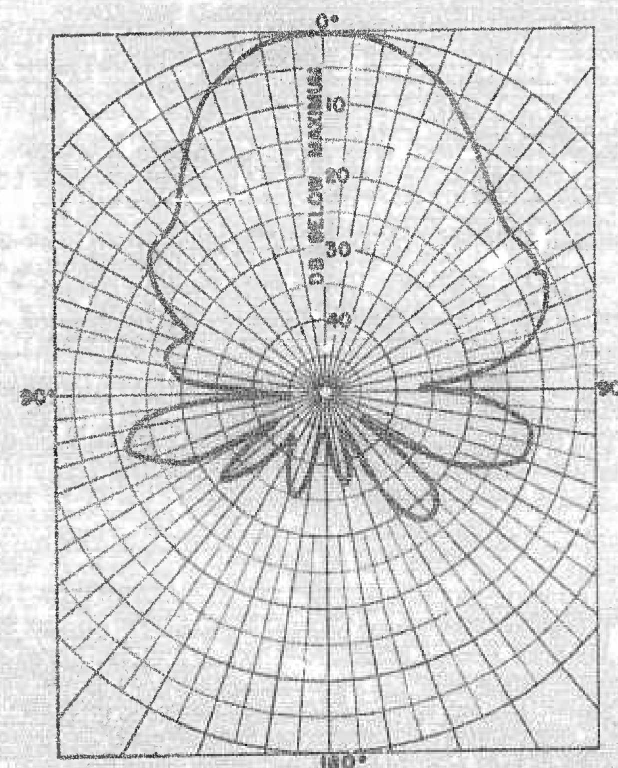


FIGURE 16. Directivity pattern, ADP type CBD 51052 hydrophone at 8 kc.

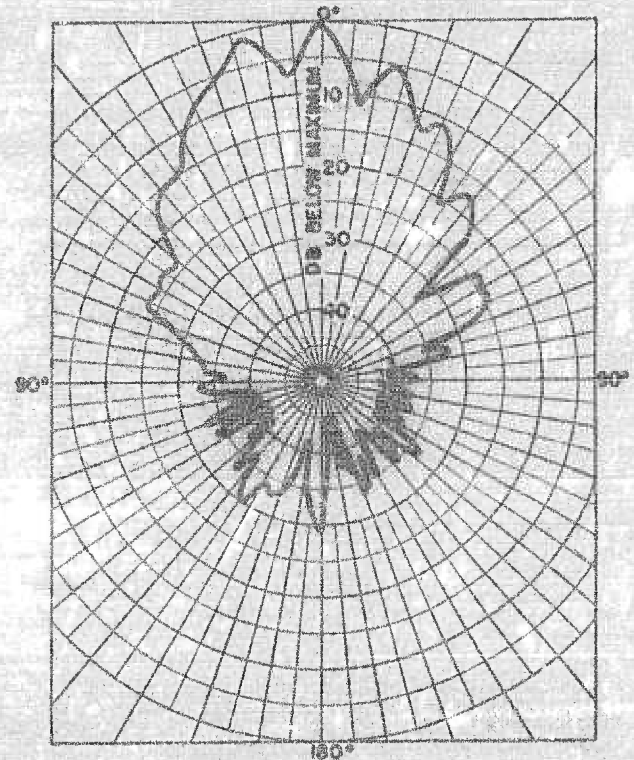


FIGURE 17. Directivity pattern, ADP type CBD 51052 hydrophone at 24 kc.

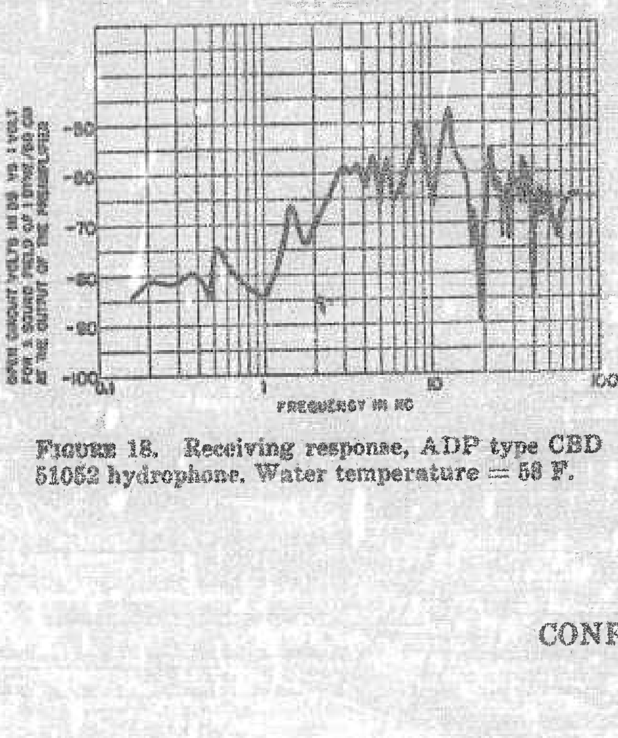


FIGURE 18. Receiving response, ADP type CBD 51052 hydrophone. Water temperature = 58 F.

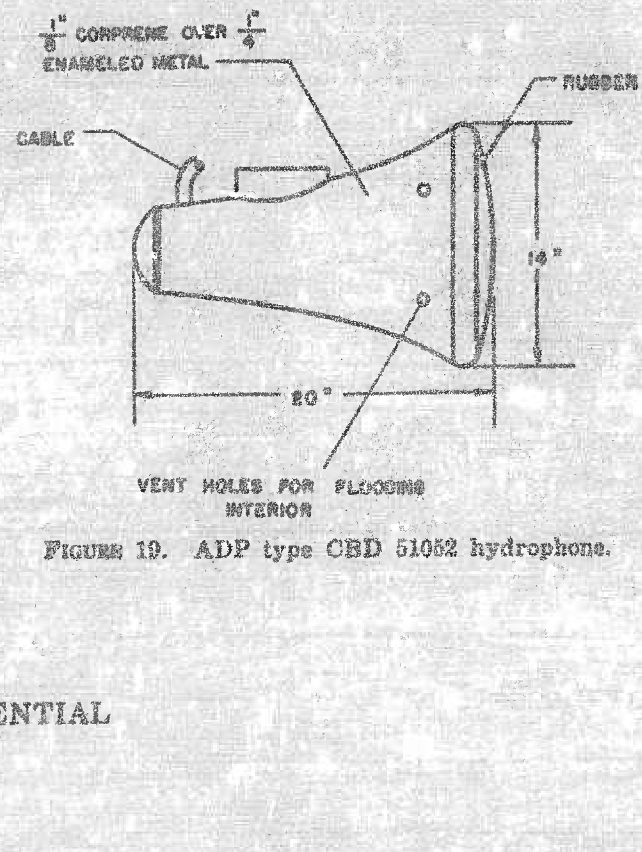


FIGURE 19. ADP type CBD 51052 hydrophone.

2.7.6 **JT Sonar-Listening Equipment**

Type: Magnetostriction.

Designer: Columbia University, Division of War Research, at the U. S. Navy Underwater Sound Laboratory, New London, Conn.

Description: The JT equipment for submarines is an improved version of the JP-1 system. USRL calibrations of the CQA 51074 (NL-124) hydrophone, which is the sound pickup unit used in this equipment, are contained in Section 6.6.3.

2.7.7 NJ Sonar-Sounding Projector (CBM 78138) (Similar to CIP 78138)

Type: Magnetostriction.

Designer and Manufacturer: Submarine Signal Company, Type No. 713C.

Reference: USRL Orlando Project No. 137, January 1945.

Application: For use on medium and lightweight ships in NJ echo-sounding equipment for depths up to 200 fathoms. Its function is to convert shock impulses from a condenser-discharge type driver to acoustic energy in the water. The projector is mounted near the keel of the ship with its diaphragm horizontal and in contact with the water. It is located adjacent to a similar type unit (CBM 78139), which serves as the receiver.

Description: The CBM 78138 projector is a magnetostrictive type consisting of a rectangular laminated nickel stack in a circular housing partially filled with oil. The position of the nickel stack is adjustable inside the projector housing to allow the active radiating face to be located exactly horizontal at the time of its installation on the ship. The projector is installed with the arrow on the back of the housing coinciding with the shorter dimension of the nickel stack and at right angles to the keel line of the ship. Polarization for the projector is furnished by the d-c component of the condenser-discharge output of the driver unit. For sketch of device see Section 2.7.8. A directivity pattern for the CBM 78138 projector with 836A driver, measured at peak pressure of pulse, is shown in Figure 20. Directivity index = approximately −12 db. Figure 21 gives an analysis of the sound field for the CBM 78138 projector with 836A driver. The water temperature = 68 F.

Weight of projector: 110 lb.

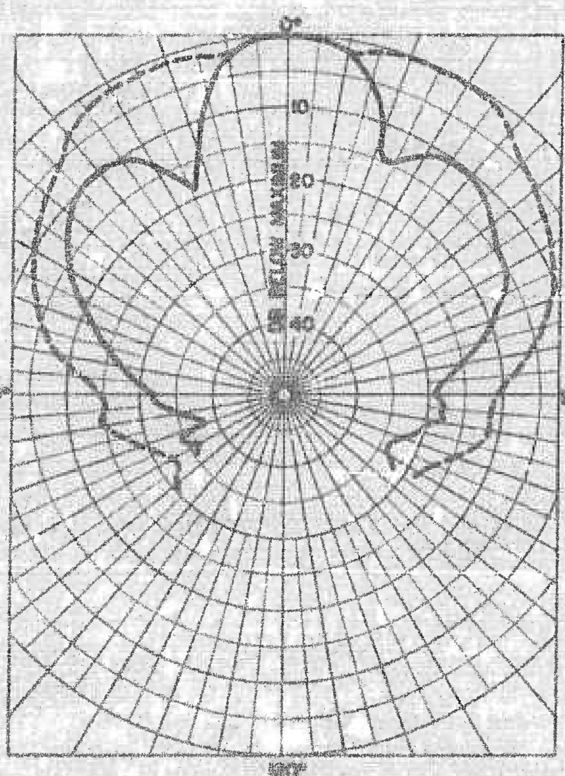


FIGURE 20. Directivity pattern. Broad beam pattern—in plane including arrow on case, narrow beam pattern—in plane at right angles to arrow on case.

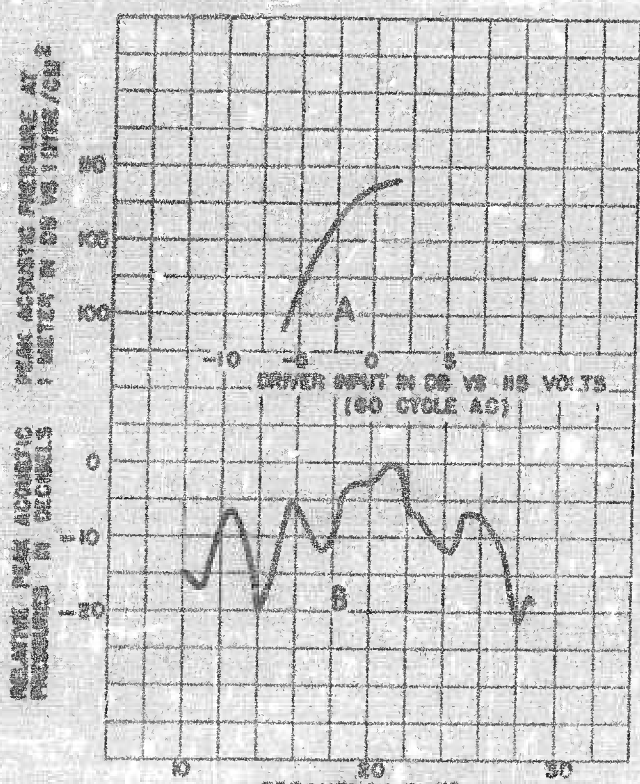


FIGURE 21. Analysis of sound field. A. Peak acoustic pressure at 1 m. B. Relative peak acoustic pressures measured in a 37-c band.

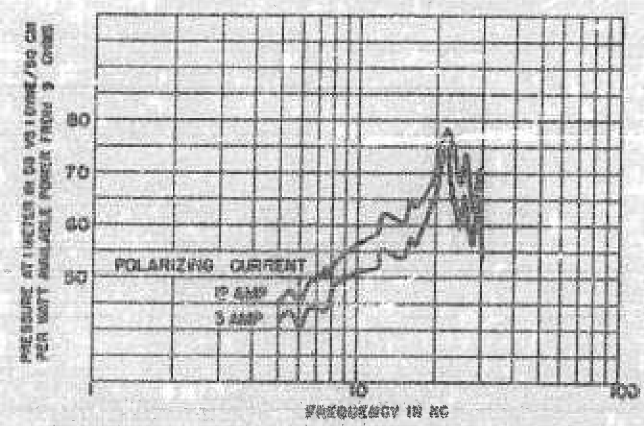


FIGURE 22. CW transmitting response, CBM 78138 projector. Water temperature = 68 F.

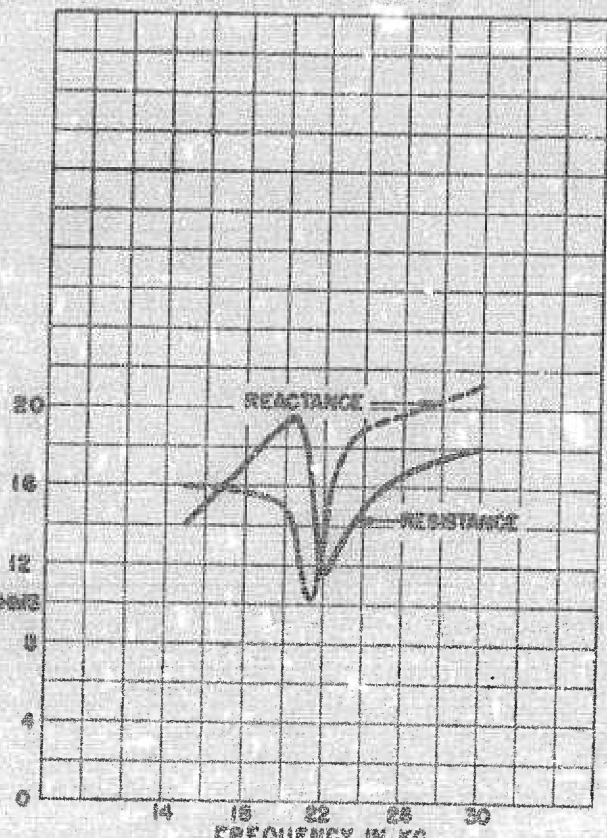


FIGURE 23. Impedance, CBM 78138 projector.

1.7.8 NJ Sonar-Sounding Projector (CIP 78139) (Similar to CBM 78139)

Type: Magnetostriction.

Designer: Submarine Signal Company.

Manufacturer: International Projector Company.

Reference: USRL Orlando Project No. 137, January 1945.

Application: For use on medium and lightweight ships in NJ echo-sounding equipment for depths up to 200 fathoms. It functions in the NJ equipment as a receiver to convert the echoes from the sea bottom from acoustic to electric energy. The projector is mounted near the keel of the ship with its diaphragm horizontal and in contact with the water. It is located adjacent to a similar type unit (CIP 78138), which serves as the transmitter to send out impulses into the water.

Description: Except for the impedance of the windings, this projector is identical with the CBM (or CIP) 78138 projector. Polarization is furnished by the residual magnetism provided by a momentary connection of 8 v dc across the windings. Weight of projector: 110 lb.

Threshold pressure at resonance: Approximately —90 db vs 1 dyne per sq cm.

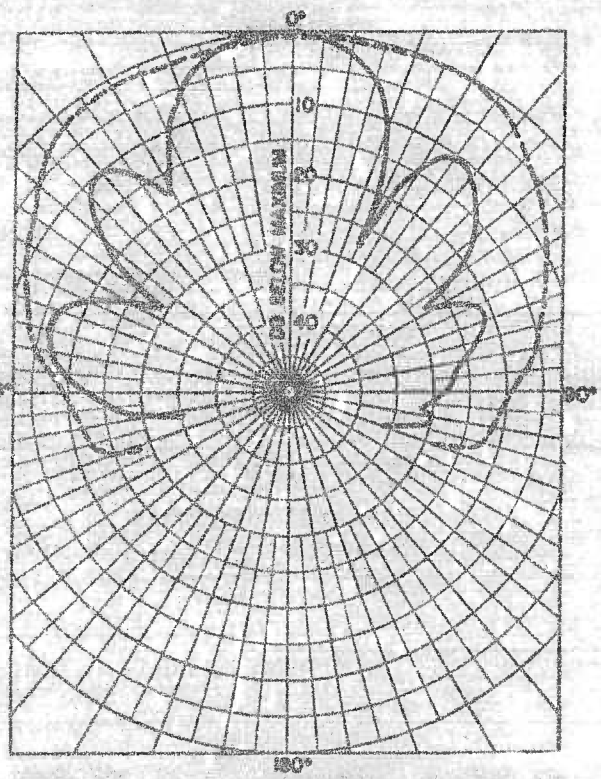


FIGURE 24. Directivity pattern at 21.34 kc. Broad beam—in plane including arrow on case, narrow beam—in plane at right angles to arrow on case. Directivity index = approximately —12 db.

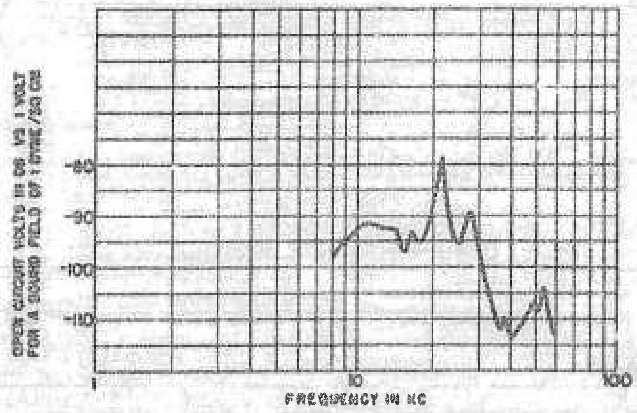


FIGURE 26. CW receiving response, CIP 78139 projector. Water temperature = 60 F. Calculated threshold at 21.8 kc = —90 db vs. 1 dyne/sq cm.

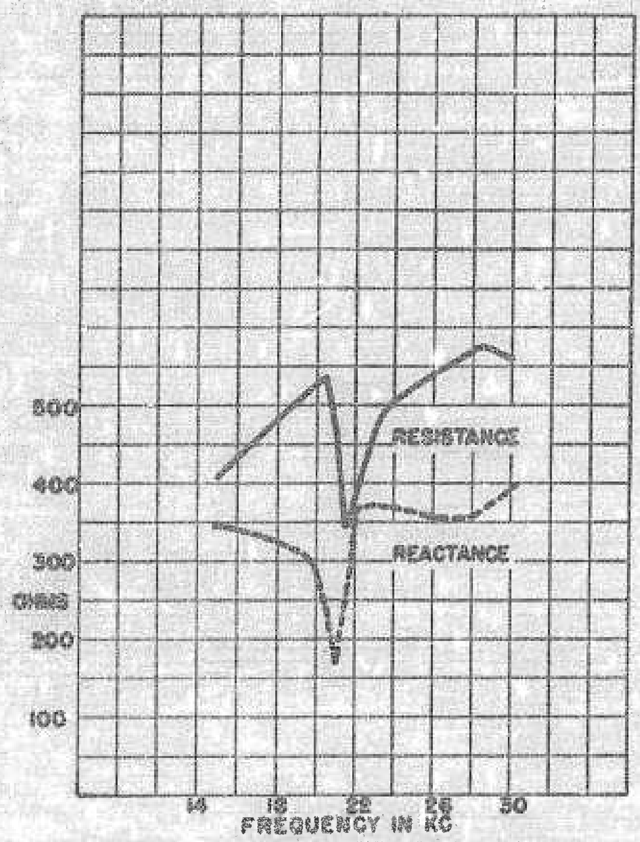


FIGURE 25. Impedance, CIP 78139 projector.

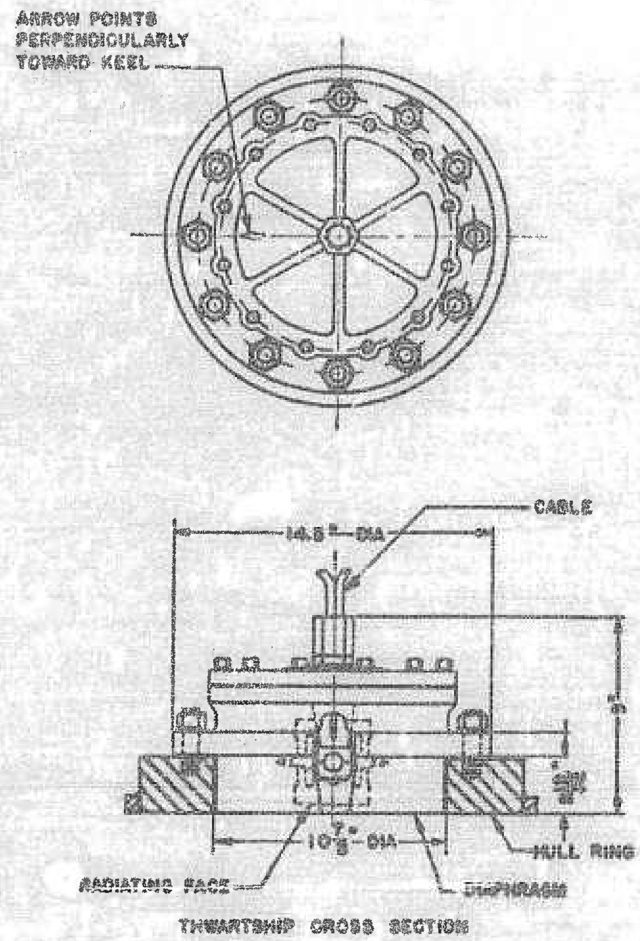


FIGURE 27. NJ sonar sounding projector CBM (CIP) 78138 and 78139.

2.7.9 NM, NMA, NMB-2 Sonar-Sounding Projector (CBM 78067)

Type: Magnetostriction.

Manufacturer: Submarine Signal Company, Type No. 763.

Reference: USRL Orlando Project No. 137, January 1945.

Application: The CBM 78067 projector is used in NM, NMA and NMB-2 echo-sounding equipments on submarines and large vessels to measure ocean depths up to 4,000 fathoms. Its function is to convert electric pulses of approximately 18 kc to acoustic energy and then receive the echoes returned from the ocean bottom or other reflecting surface.

Description: The CBM 78067 projector is a rectangular magnetostrictive-type unit with dimensions 10⅛x20 in. The projector is mounted by means of a flange 13.5x23 in. on the back of the unit. The active driving elements are nickel tubes which have one end imbedded in the rectangular steel diaphragm. A coil surrounds each nickel tube. These coils carry the d-c polarizing current (approximately 9.5 amp) and the pulses of 18-kc driving current.

Impedance at resonance (18.3 kc): $96 + j155$ ohms.

Efficiency at resonance: —10.0 db vs ideal.

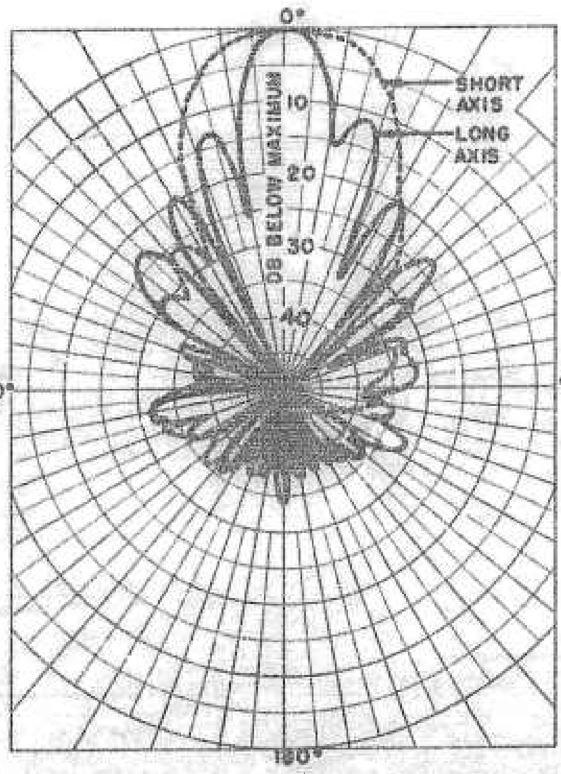


FIGURE 28. Directivity patterns, CBM 78067 projector at 18.3 kc. Directivity index = —20.8 db.

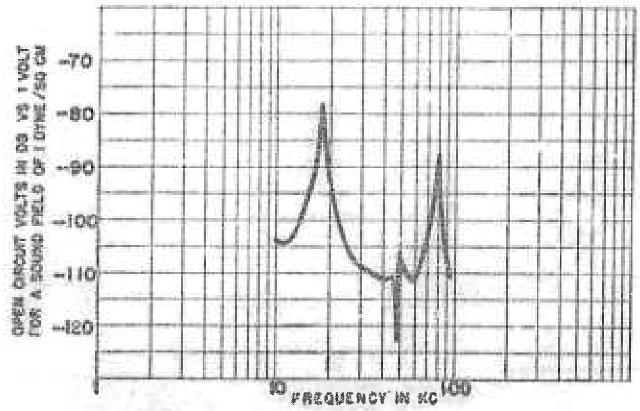


FIGURE 30. Receiving response, CBM 78067 projector. Water temperature = 62 F. Q = 34. Calculated threshold at 18.3 kc = —97 db vs 1 dyne/sq cm.

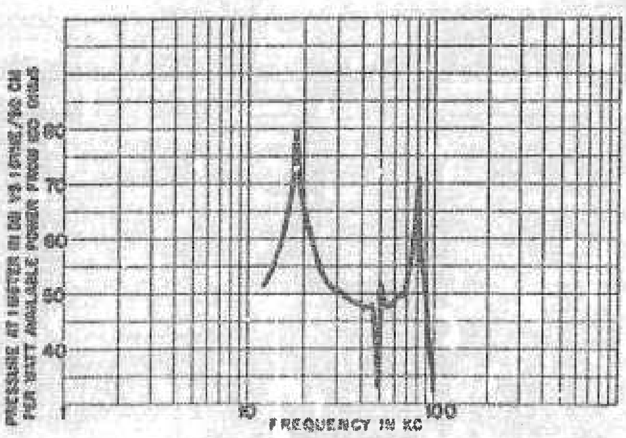


FIGURE 29. Transmitting response, CBM 78067 projector. Water temperature = 62 F. Q = 37.

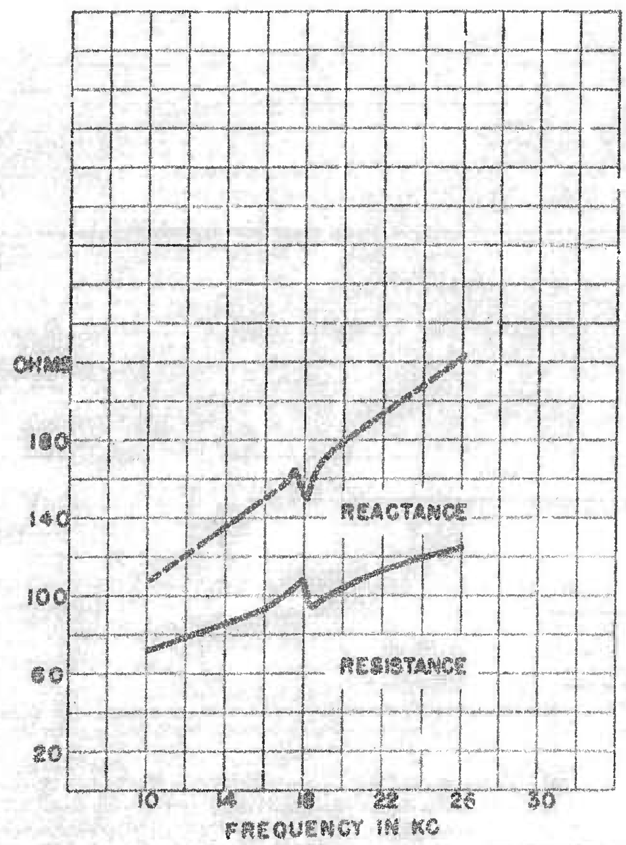


FIGURE 31. Impedance, CBM 78067 projector.

2.7.10 NM-2, NM-5 Sonar-Sounding Projector (CBM 78016A)

Type: Magnetostriction.

Manufacturer: Submarine Signal Company, Type No. 551B.

Reference: USRL Orlando Project No. 137, January 1946.

Application: The CBM 78016A projector is used in the NM-2, and NM-5 echo-sounding equipments for medium and large vessels. Its function is to convert electric pulses of approximately 18 kc to acoustic energy and then receive the echoes returned from the ocean bottom or other reflecting surface. The projector is mounted in the hull of the ship near the keel with the projector diaphragm horizontal.

Description: The CBM 78016A projector is a magnetostrictive-type unit in a cylindrical housing. The active driving elements are a group of nickel tubes which have one end imbedded in a circular steel plate serving as the diaphragm. A coil surrounds each of these tubes. These coils carry the d-c polarizing current (approximately 7.5 amp) and the pulses of 18-kc driving current. They also carry the receiving voltage generated when the returning echo strikes the diaphragm. Weight of projector: 225 lb.

Impedance at resonance (18.4 kc): 126 + j184 ohms.

Efficiency at resonance: —10.5 db vs ideal.

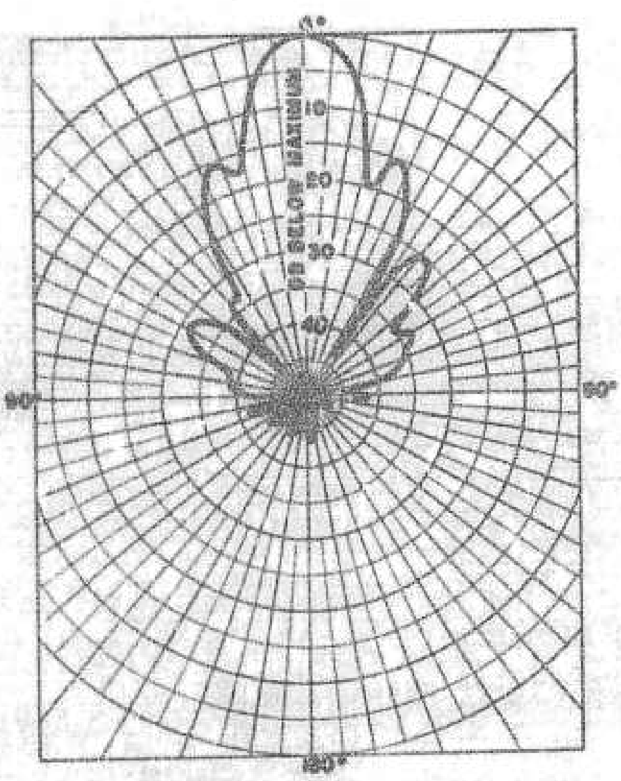


Figure 32. Directivity pattern, CBM 78016A projector at 18.7 kc. Directivity index = —21.7 db.

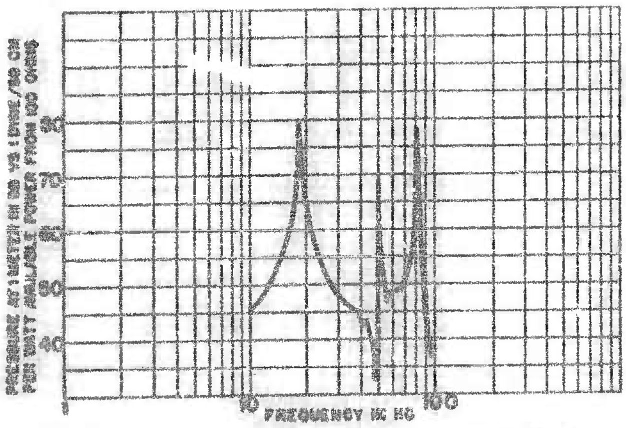


FIGURE 33. Transmitting response, CBM 78016A projector. Water temperature = 63 F. Q = 45.

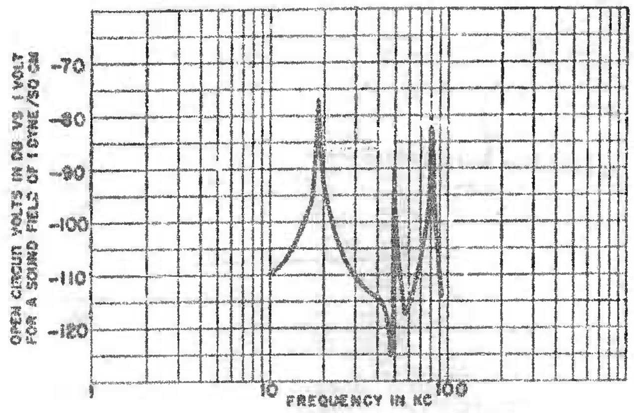


FIGURE 34. Receiving response, CBM 78016A projector. Water temperature = 63 F. Q = 41. Calculated threshold at 18.7 kc = −97 db vs 1 dyne/sq cm.

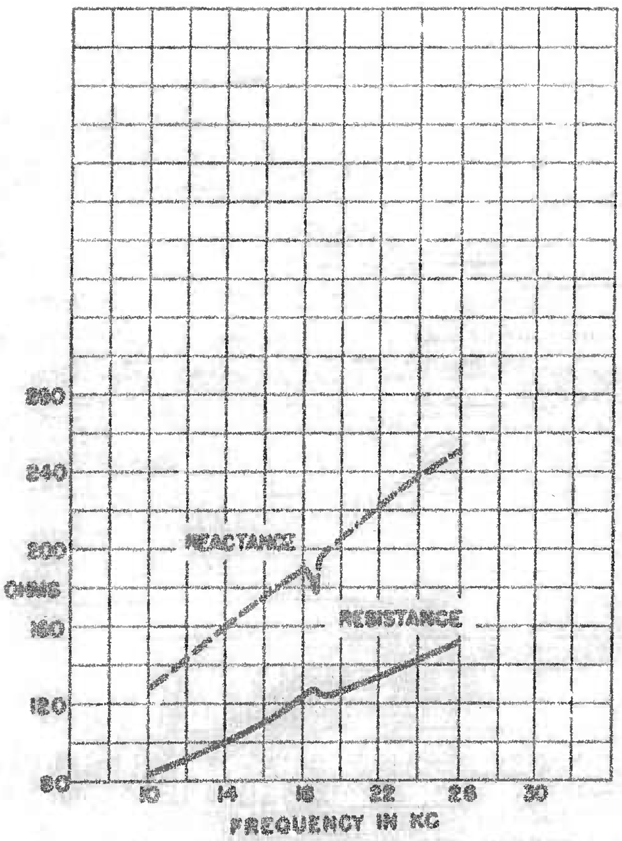


FIGURE 35. Impedance, CBM 78016A projector.

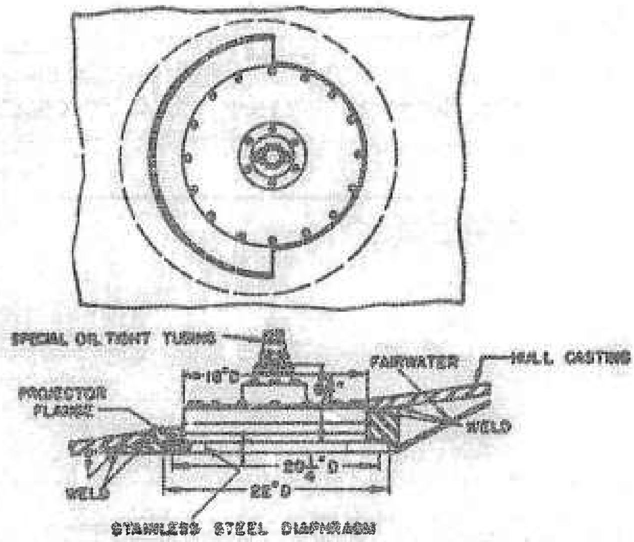


FIGURE 36. CBM 78016A projector.

2.7.11 NMB-1 Sonar-Sounding Projector (CRV 78133)

Type: Magnetostriction.

Designer and Manufacturer: RCA Victor Division of the Radio Corporation of America, Type No. MI 8983.

Reference: USRL Orlando Project No. 137, January 1945.

Application: The CRV 78133 is used in the NMB-1 echo-sounding equipment for large A/S ships for measuring water depths up to 4,000 fathoms.

Description: The CRV 78133 projector is a magnetostrictive type with permanent magnets in a rectangular housing. The active driving elements are 170 nickel tubes which have one end imbedded in the heavy rectangular steel plate serving as the diaphragm. The coil assembly in the projector consists of a series-parallel connection of identical coils over the nickel tubes. These coils carry the driving current actuating the projector. Polarization is produced by 20 permanent magnets in a structure mounted just above the nickel tubes. The complete structure is filled with oil up to ½ in. from the top plate. Weight of projector: 270 lb.

Impedance at resonance (18.7 kc): 42.5 + j154 ohms.

Efficiency at resonance (18.7 kc): —16.3 db vs ideal.

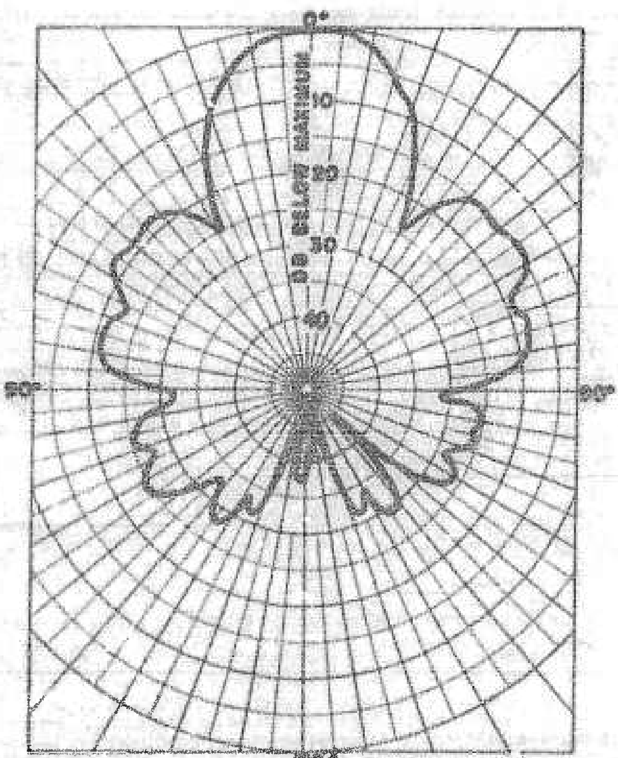


FIGURE 37. Directivity pattern, CRV 78133 projector at 18.7 kc. Directivity index = —16.2 db.

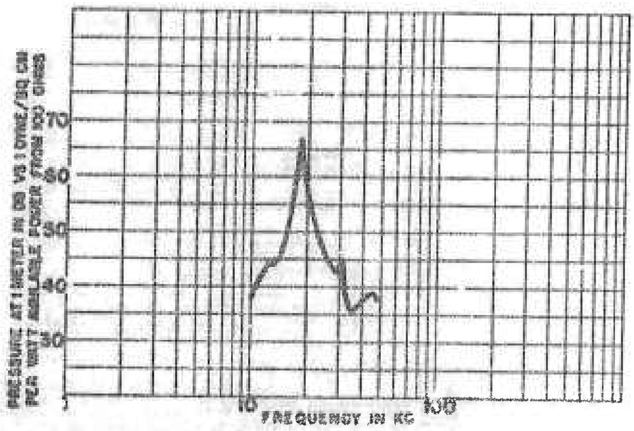


FIGURE 38. Transmitting response, CRV 78133 projector. Water temperature = 62 F. Q = 17.8.

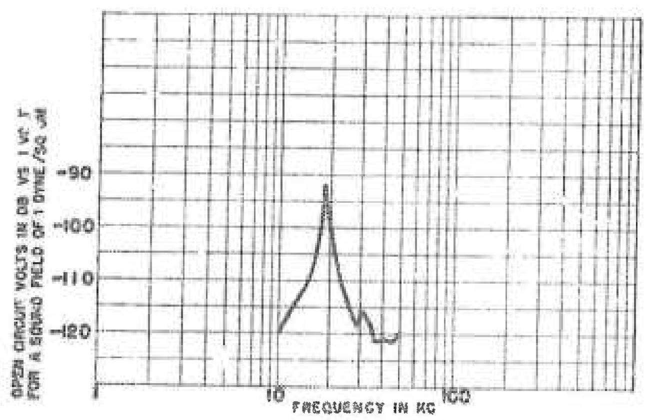


FIGURE 39. Receiving response, CRV 78133 projector. Water temperature = 62 F. Calculated threshold at 18.7 kc = −86 db vs 1 dyne/sq cm.

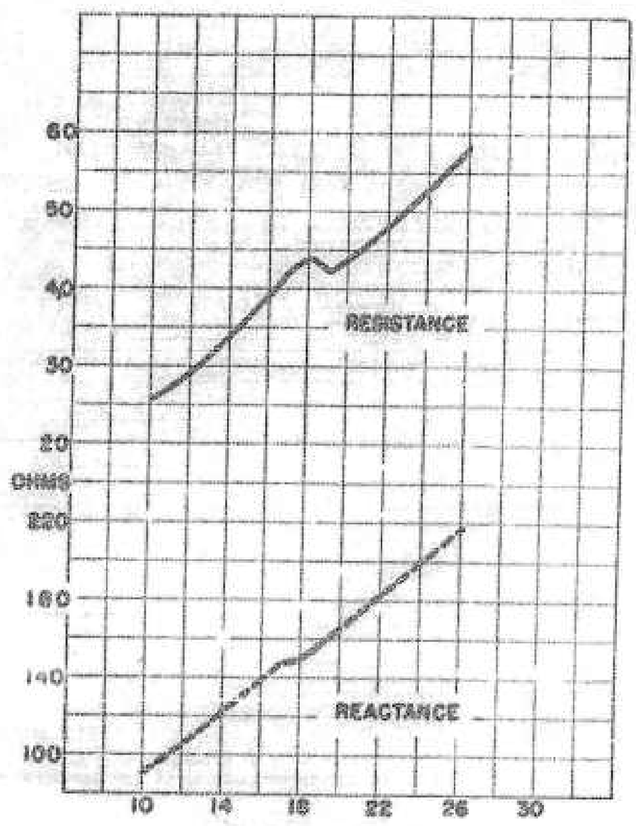


FIGURE 40. Impedance, CRV 78133 projector.

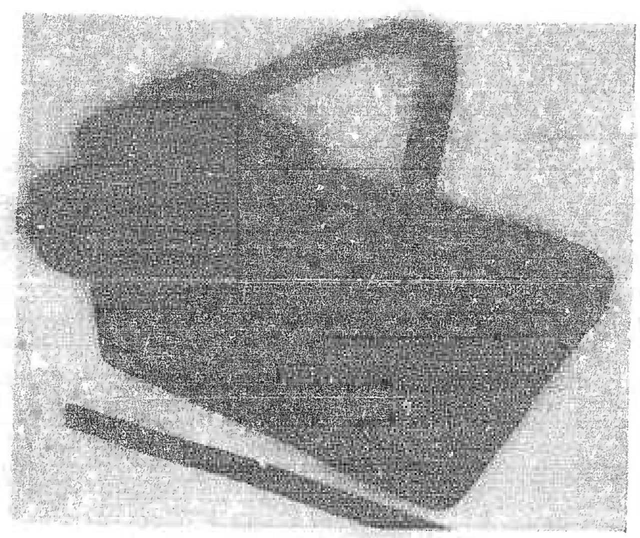


FIGURE 41A. CRV 78133 projector.

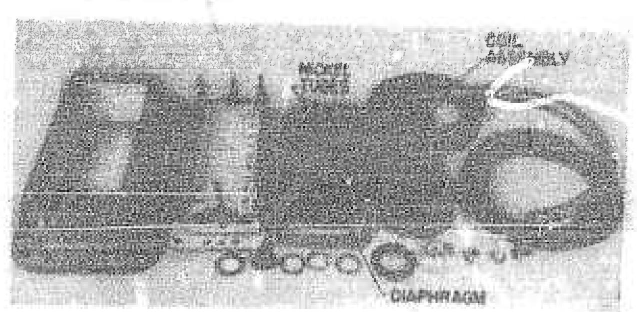


FIGURE 41B. CRV 78133 projector, component parts.

2.7.12

NMC Sonar-Sounding Projectors (CRV 78169 and CRV 78170)

Type: Magnetostriction.

Manufacturer: Radio Corporation of America, Type MI 16712A and MI 16712B.

Reference: NDRC Report No. 6.1-sr1130-1985, January 16, 1945.[72]

Application: These projectors are designed for use in the NMC echo-sounding equipment for depths up to 2,000 fathoms. One of the projectors is for sounding in shallow water and the other for sounding in deep water. The function of the projector in the NMC equipment is to transmit a short pulse of 18-kc supersonic energy into the water and then receive the echo returned from the ocean bottom or from a reflecting surface.

Description: The NMC projector is a magnetostrictive type consisting of a heavy steel plate or diaphragm in a circular steel housing. Imbedded in this plate are 70 nickel tubes which act as driving elements. Above these tubes is mounted a permanent magnet. The coil structure in the projector consists of a series-parallel connection of identical coils with one such coil fitting over each nickel tube. The CRV 78170 projector for deep water sounding is filled with CO_2 gas under 6 lb per sq in. pressure. The CRV 78169 projector for shallow water sounding is identical with the CRV 78170, except that the CO_2 gas is replaced by oil for damping.

Efficiency at resonance (CRV 78169): —14 db vs ideal.

Efficiency at resonance (CRV 78170): —10 db vs ideal.

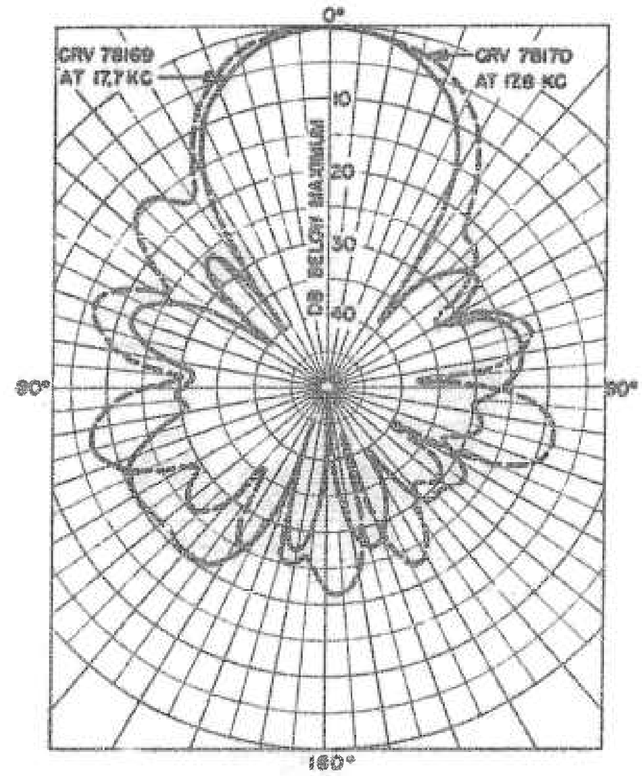


FIGURE 42. Directivity patterns, CRV 78169 and 78170. Directivity index: CRV 78169 = —15.8 db, CRV 78170 = —14.2 db.

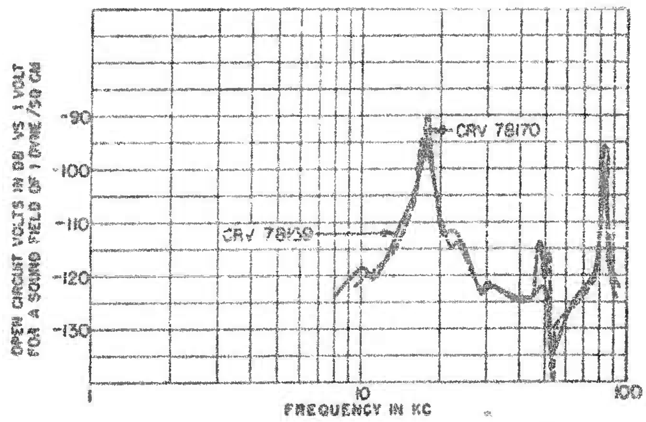


FIGURE 44. Receiving response, CRV 78169 and 78170. Water temperature = 64 F. Q: CRV 78169 = 22, CRV 78170 = 48. Calculated threshold: CRV 78169 at 17.7 kc = —93 db vs 1 dyne/sq cm, CRV 78170 at 17.8 kc = —89 db vs 1 dyne/sq cm.

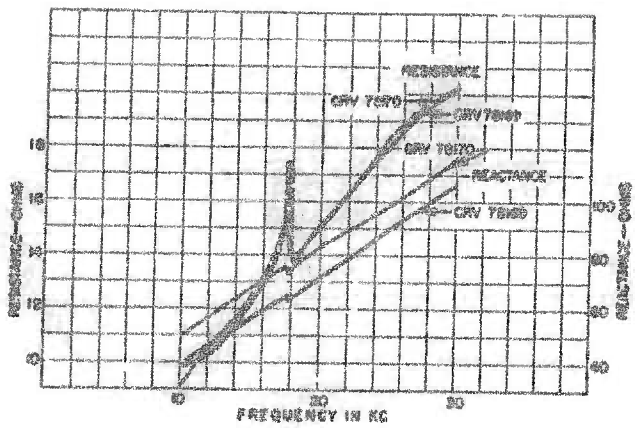


FIGURE 45. Impedance, CRV 78169 and 78170.

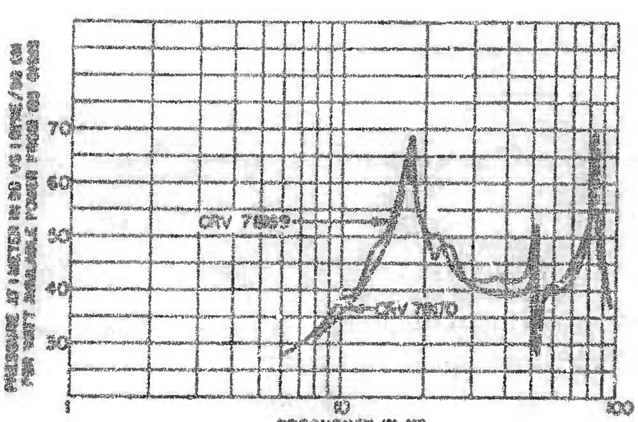


FIGURE 43. Transmitting response, CRV 78169 and 78170. Water temperature = 64 F. Q: CRV 78169 = 22, CRV 78170 = 47.

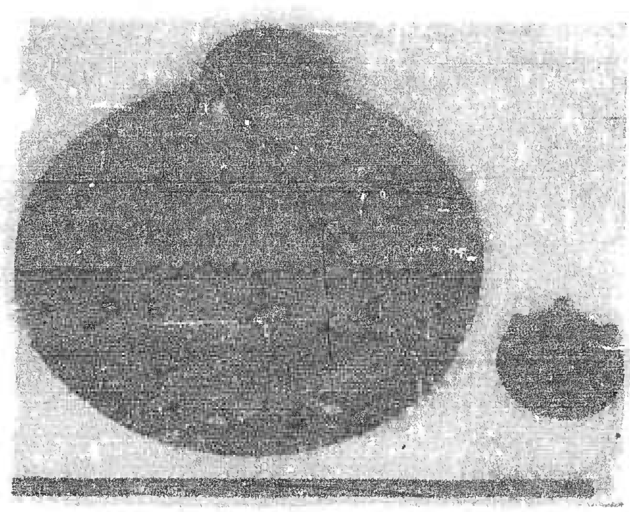


FIGURE 46. CRV 78169 or 78170 projector.

2.7.13 NMC-1 Sonar-Sounding Projector (CBM 78203)

Type: Magnetostriction.

Manufacturer: Submarine Signal Company, Type No. 943.

Reference: USRL Orlando Project No. 137, January 1945.

Application: The CBM 78203 projector is used in the NMC-1 echo-sounding equipment for use on ships to measure ocean depths up to about 4,000 fathoms. Its function is to convert electric pulses of approximately 18 kc to acoustic energy in the water and then receive the echoes returned from the ocean bottom or other reflecting surface. The projector is mounted near the keel of the ship with the diaphragm horizontal and in contact with the water.

Description: The CBM 78203 projector is a magnetostrictive type with permanent magnets. The active driving elements are 148 nickel tubes which have one end imbedded in the heavy circular steel plate serving as the diaphragm in contact with the water. Each tube is surrounded by a coil which carries the driving current in transmitting the supersonic pulse and also the receiving voltage generated when the returning echo strikes the diaphragm. The complete structure is filled with CO_2 gas under 30 lb per sq in. pressure. Weight of projector: 140 lb.

Impedance at resonance (18.4 kc): $43.2 + j103$ ohms.

Efficiency at resonance: —11.5 db vs ideal.

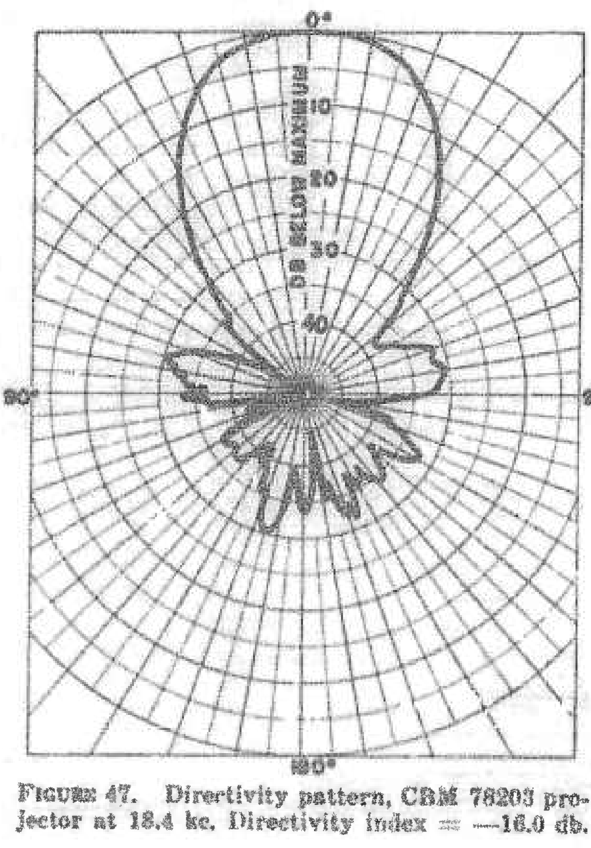


FIGURE 47. Directivity pattern, CBM 78203 projector at 18.4 kc. Directivity index = —16.0 db.

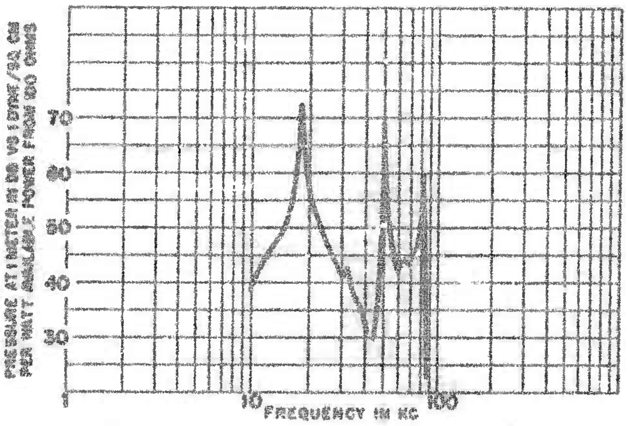


FIGURE 48. Transmitting response, CBM 78203 projector. Water temperature = 63 F. Q = 33.

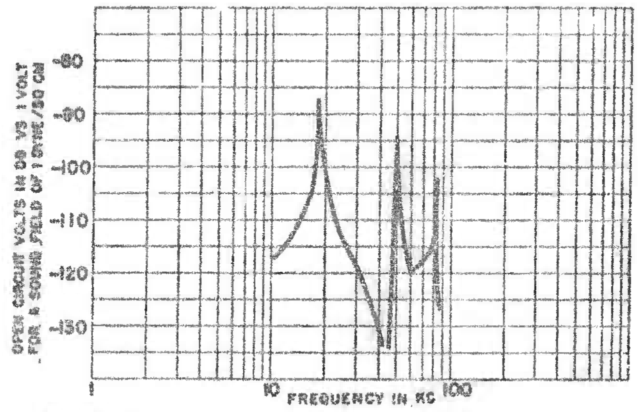


FIGURE 49. Receiving response, CBM 78203 projector. Water temperature = 63 F. Q = 33. Calculated threshold at 18.4 kc = —86 db vs 1 dyne/sq cm.

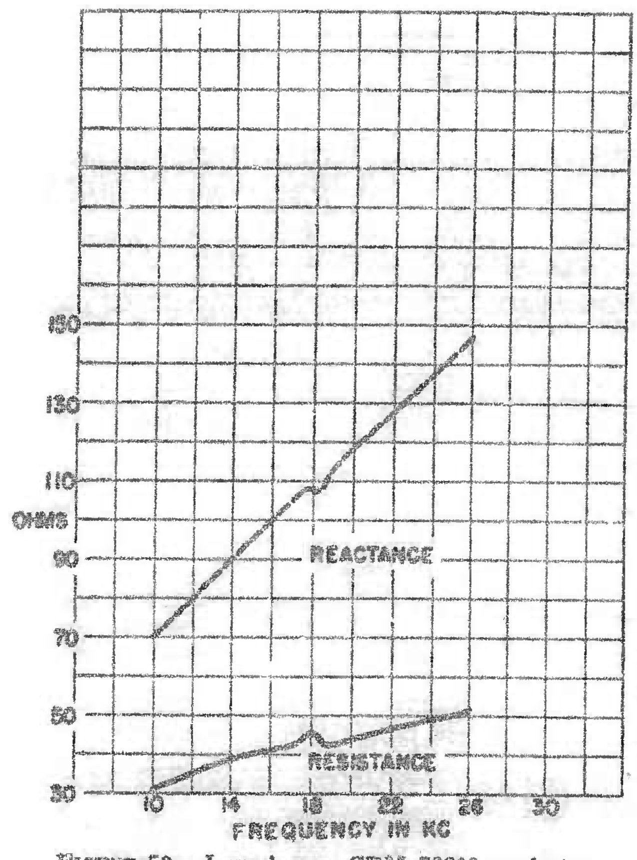


FIGURE 50. Impedance, CBM 78203 projector.

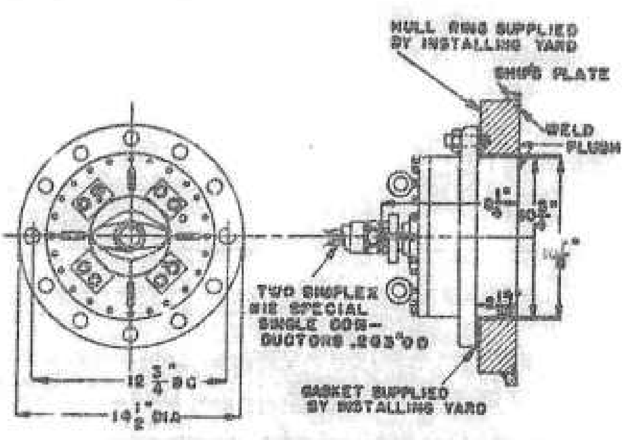


FIGURE 51. CBM 78203 projector.

2.7.14 WEB (WCA-2) Sonar-Sounding Projector (CBM 78214)

Type: Magnetostriction.

Designer and Manufacturer: Submarine Signal Company, Type No. 947.

Reference: NDRC Report No. 6.1-sr1130-1837, October 13, 1944.[71]

Application: The CBM 78214 projector is used for echo sounding in the WCA-2 and the WEB equipments for submarines. Its function is to convert electric pulses of approximately 24 kc to acoustic energy in the water and then receive the echoes returned from the ocean bottom or other reflecting surface. This projector is used in combination with the CBM 78212 echo-ranging and listening unit in the WEB equipment and in combination with the CBM 78212 and CBM 78213 projectors in the WCA-2 equipment.

Description: This unit is a magnetostrictive type consisting of a laminated nickel stack in a rectangular housing. A steel plate ⅝ in. thick serves as the diaphragm in contact with the water. After assembly the unit is filled with an inert gas under pressure of approximately 6 lb per sq in.

Efficiency at resonance: —11 db vs ideal.

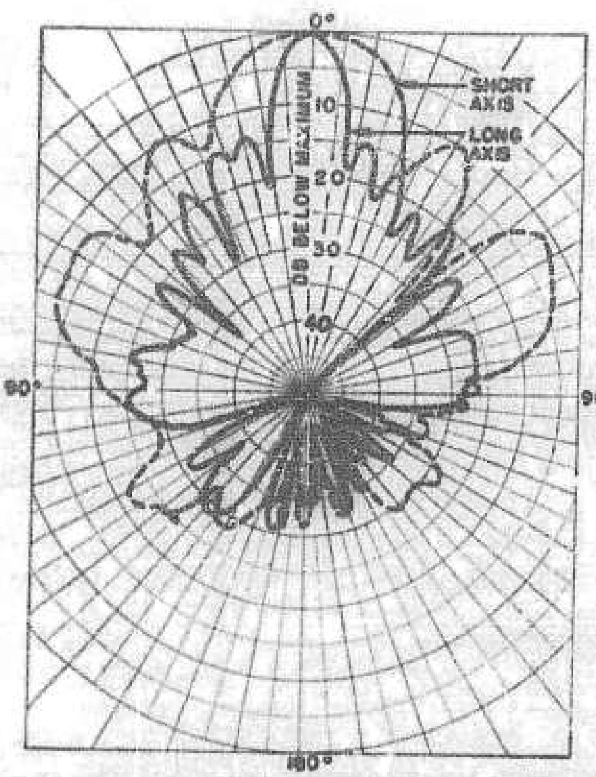


FIGURE 52. Directivity patterns, CBM 78214 projector at 23.4 kc. Directivity index = —23.1 db.

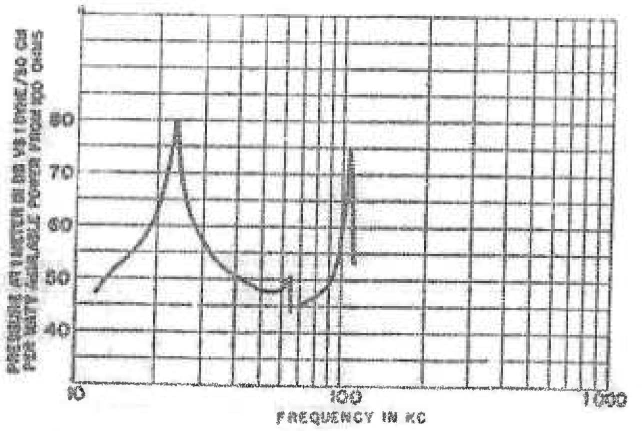


FIGURE 53. Transmitting response, CBM 78214 projector. Water temperature = 82 F.

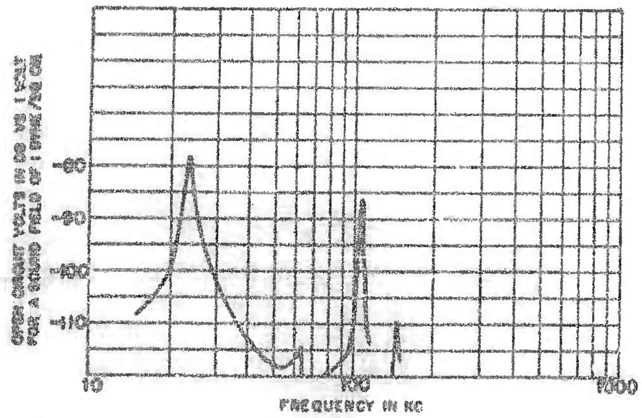


FIGURE 54. Receiving response, CBM 78214 projector. Water temperature = 80 F. Q at 23.4 kc = 32, at 106.7 kc = 61. Calculated threshold at 23.4 kc = —96 db vs 1 dyne/sq cm.

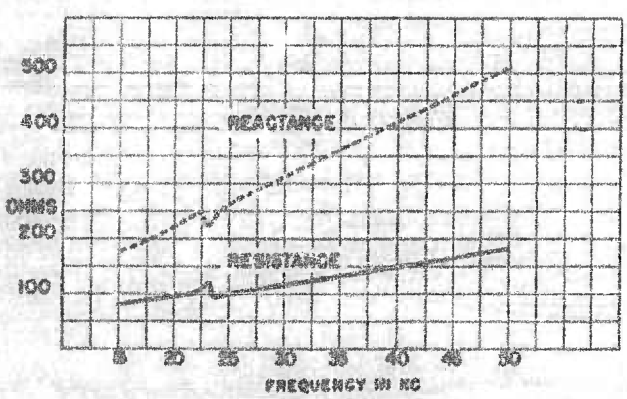


FIGURE 55. Impedance, CBM 78214 projector.

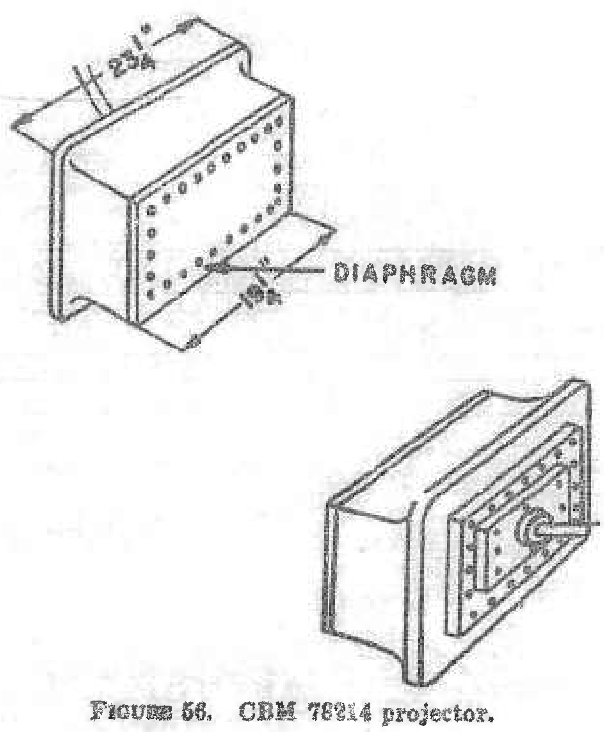


FIGURE 56. CBM 78214 projector.

2.7.15 QBE, QBE-1 (JK-9) Sonar-Ranging Projector (CBM 78142)

Type: X-Cut Rochelle Salt Crystal.
Manufacturer: Submarine Signal Company, Type No. 865.
Reference: NDRC Report No. C4-sr20-115, June 20, 1942.[43]
USRL Orlando Project No. 137, January 1945.

Application: The CBM 78142 projector is used as the transducer in the JK-9 sound listening equipment to detect the presence of high-frequency underwater sound originating from propellers or other moving machinery of vessels. It is also a major unit in the QBE and QBE-1 equipments for echo ranging and listening on small A/S ships. The projector is housed in a torpedo-shaped, or fish-type, retractable dome.

Description: The CBM 78142 projector is banjo-shaped, approximately 13½ in. in diameter by 5 in. deep. The active elements, consisting of X-cut Rochelle salt crystals, are mounted on a steel backing plate. The space between the crystals and the projector face is filled with air-free dehydrated castor oil. The crystals are connected in parallel. This projector is not arranged for BDI. When this type unit is split for BDI operation, it is coded CBM 78142A (865A).

No transmitting response on this device was taken by USRL.

Efficiency at 24 kc: —3.7 db vs ideal.

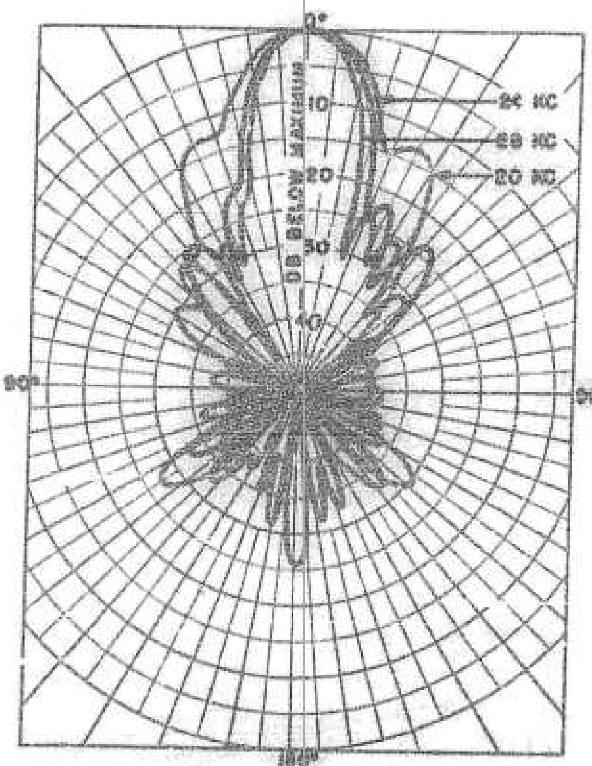


FIGURE 57. Directivity patterns, CBM 78142 projector. Directivity index: at 20 kc = −20.2 db, at 24 kc = −21.7 db, at 28 kc = −23.2 db.

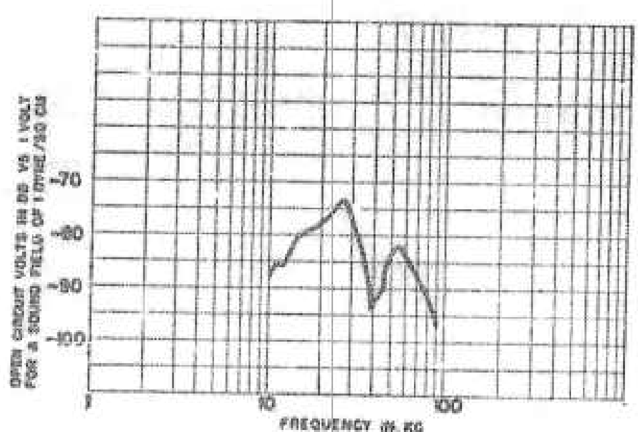


FIGURE 58. Receiving response, CBM 78142 projector. Water temperature = 62 F. Calculated threshold at 20 to 28 kc = −102.5 db vs 1 dyne/sq cm.

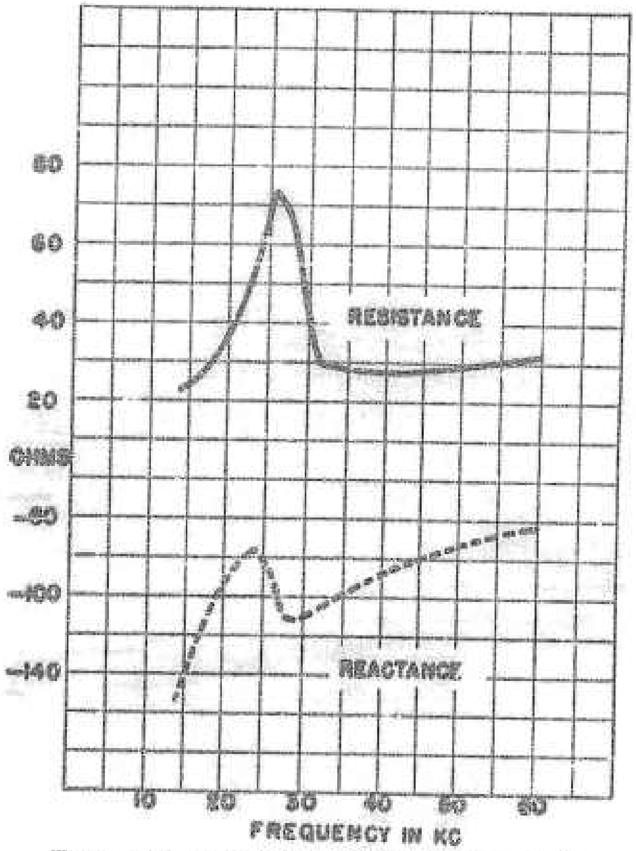


FIGURE 59. Impedance, CBM 78142 projector.

2.7.16 QBE-2, QBE-3 Sonar-Ranging Projector (CBM 78142A)

Type: X-Cut Rochelle Salt Crystal.

Manufacturer: Submarine Signal Company, Type No. 865A.

Reference: USRL Orlando Project No. 137, January 1945.

Application: The CBM 78142A projector is used as a topside transducer in the QBE-2 equipment for submarines and is a major unit in the QBE-3 equipment for small A/S ships. When used with the QBE-3 equipment, the projector is housed in a torpedo-shaped, or fish-type, retractable dome.

Description: The CBM 78142A projector is a banjo-shaped transducer approximately 13½ in. in diameter by 5 in. deep. The active elements, consisting of X-cut Rochelle salt crystals, are mounted on a steel backing plate. The space between the crystals and the projector face is filled with air-free dehydrated castor oil. The crystals are connected in parallel and the unit is split for BDI operation. This unit is similar to the CBM 78142 (865) projector, except that the latter is not arranged for BDI.

Efficiency at 24 kc: —3.7 db vs ideal.

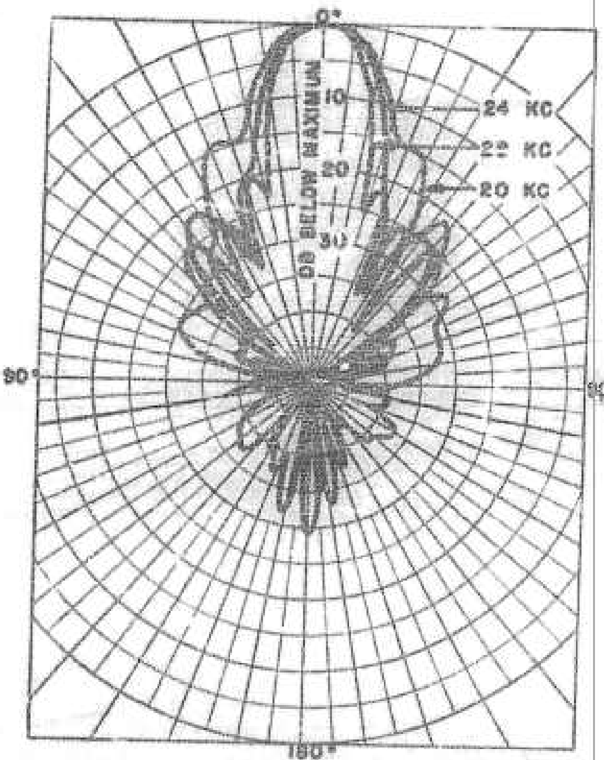


FIGURE 60. Directivity patterns, CBM 78142A projector. Directivity index: at 20 kc = —21.2 db, at 24 kc = —22.5 db, at 28 kc = —24.2 db.

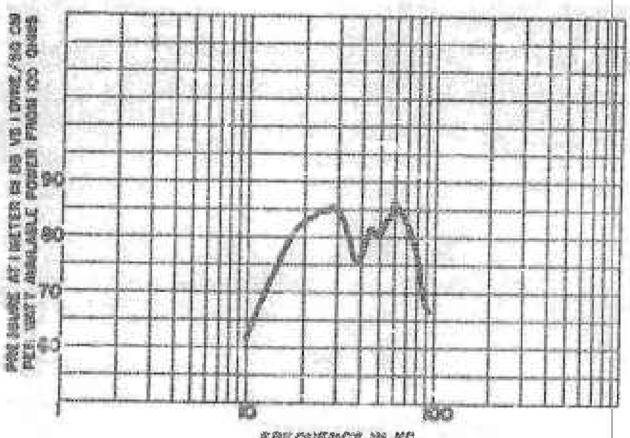


FIGURE 61. Transmitting response, CBM 78142A projector. Water temperature = 62 F.

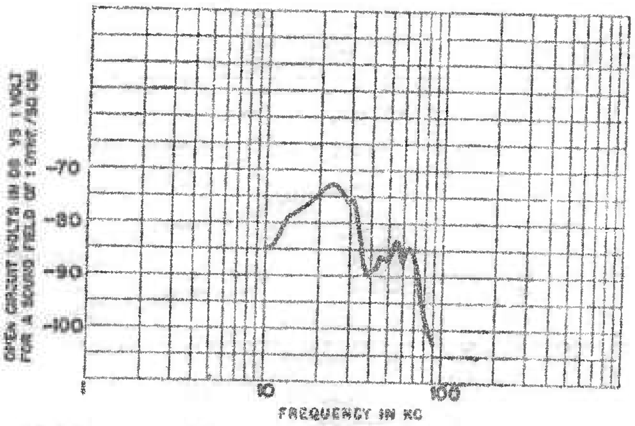


FIGURE 62. Receiving response, CBM 78142A projector. Water temperature = 62 F. Calculated threshold at 20 to 28 kc = —103 db vs 1 dyne/sq cm.

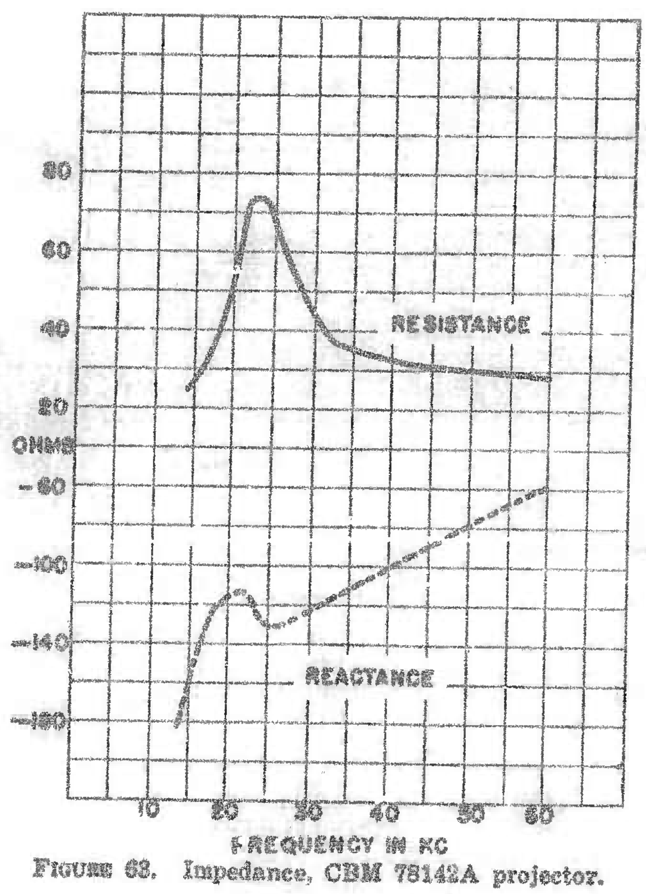


FIGURE 63. Impedance, CBM 78142A projector.

2.7.17 QBF Sonar-Ranging Projector (CW 78178)

Type: 45° Y-Cut Rochelle Salt Crystal.

Designer: Bell Telephone Laboratories.

Manufacturer: Western Electric Company, Type No. D-163462.

Reference: NDRC Report No. 6.1-sr1130-1634, July 5, 1944.[58]

Application: The CW 78178 unit is used as the projector in QBF, QJA, or QJB echo-ranging equipments for ranging on objects at distances up to 10,000 yd. The CW 78178 projector is interchangeable with the CW 78207 projector.

Description: The active elements in the CW 78178 projector consist of 45° Y-cut Rochelle salt crystals mounted on a steel plate with resonators to sharpen the tuning. The projector is rectangular in shape and is intended for use in a retractable-type dome. The active area in contact with the water is approximately 10½x10½ in. The CW 78178 is a four-wire projector split for BDI operation with the electrical connections to each half of the projector brought out separately. Weight: Approximately 200 lb.

Efficiency at 24 kc: —3.6 db vs ideal.

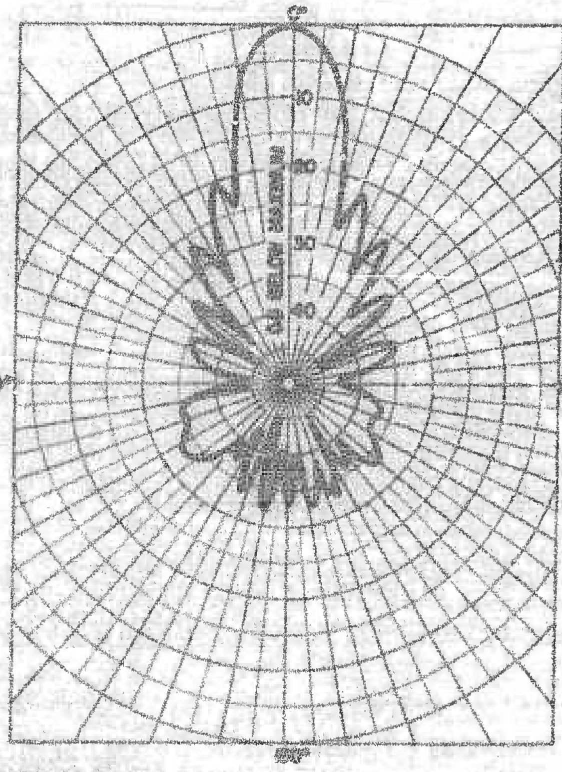


FIGURE 64. Directivity pattern, CW 78178 projector at 24 kc. Connected parallel aiding. Directivity index = —23.4 db.

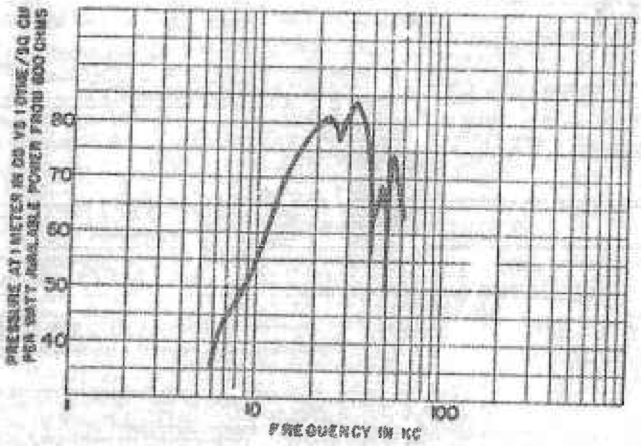


FIGURE 65. Transmitting response, CW 78178 projector. Connected parallel aiding. Water temperature = 46 F.

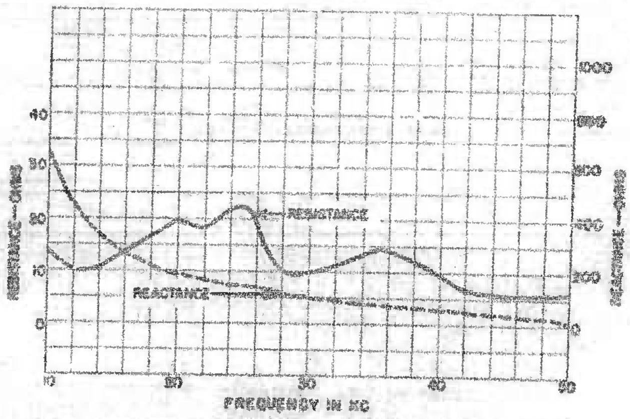


FIGURE 67. Impedance, CW 78178 projector. Connected parallel aiding.

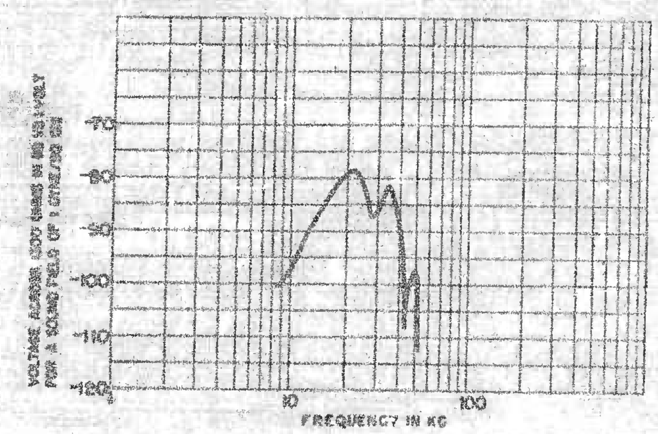


FIGURE 66. Receiving response, CW 78178 projector. Connected parallel aiding. Water temperature = 46 F. Calculated threshold at 24 kc = —102.5 db vs 1 dyne/sq cm.

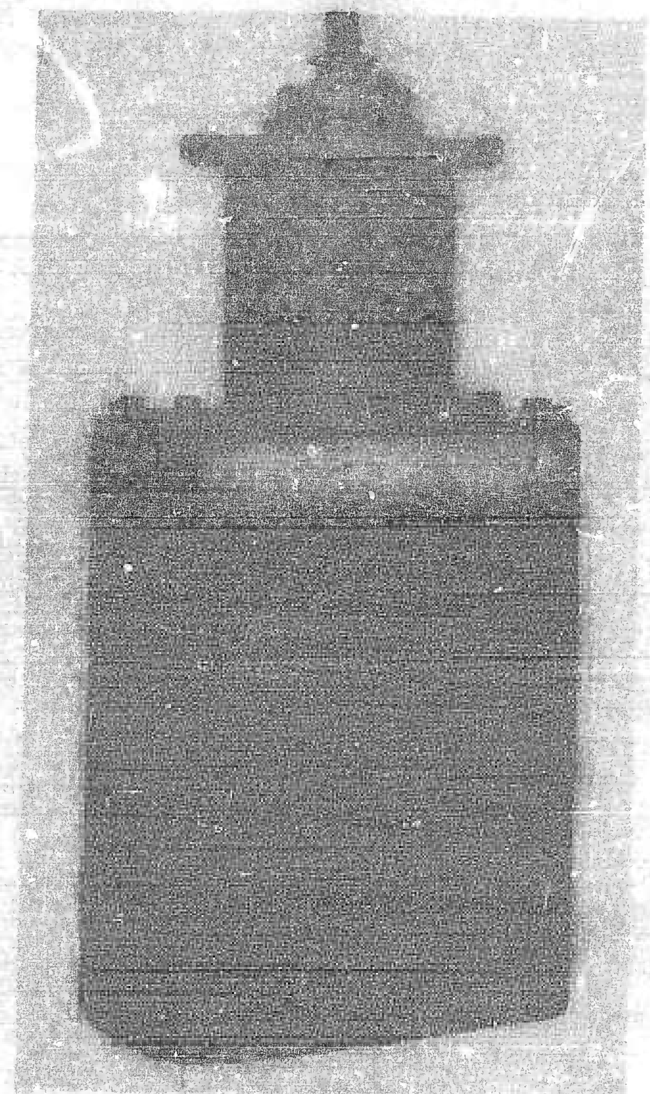


FIGURE 68. CW78178 projector.

2.7.18 QBG Sonar-Ranging Projector (CFF 78187)

Type: 45° X-Cut Rochelle Salt Crystal.

Manufacturer: Freed Radio Corporation.

Reference: NDRC Report No. 6.1-sr20-941, July 21, 1943.[58]

Application: The CFF 78187 projector is a major unit in the QBG echo-ranging equipment for landing craft. The unit is tiltable and, when trained vertically downward, may be used for depth sounding. In the QBG equipment the projector is shock-driven by a condenser-discharge type driver and operates in the 22 to 26 kc range. The projector is used for both transmitting and receiving. It is preferably mounted in a well in the boat but may be hung over the side. This unit normally is used in a torpedo-shaped dome.

Description: This projector consists of a number of 45° X-cut Rochelle salt crystal units ¼x1x1½ in. mounted on a heavy plate. Cork spacers are inserted between the crystal units. The driver unit is designed to operate from one 6-v, 120-amp-hr storage battery with a genemotor or Vibropack, or it may be run from dry batteries.

Efficiency at 25 kc: —5 db vs ideal.

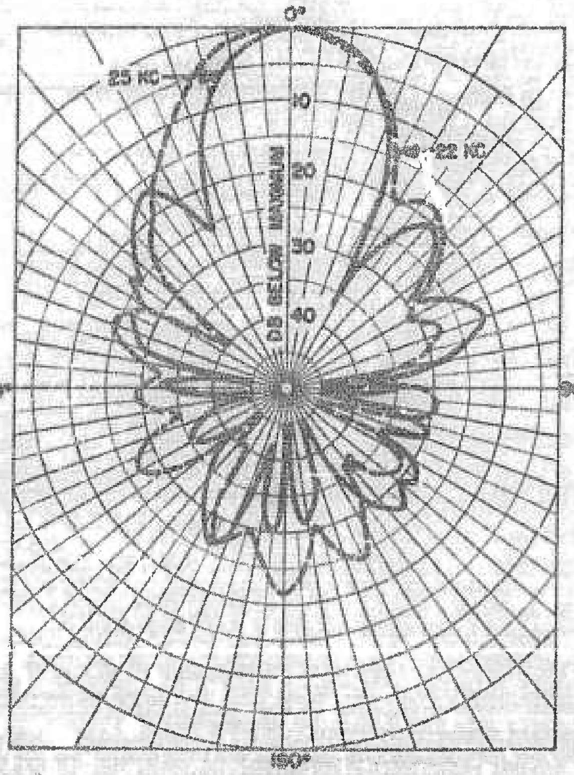


FIGURE 69. Directivity patterns, CFF 78187 projector. Directivity index: at 22 kc = —17.3 db, at 25 kc = —18.5 db.

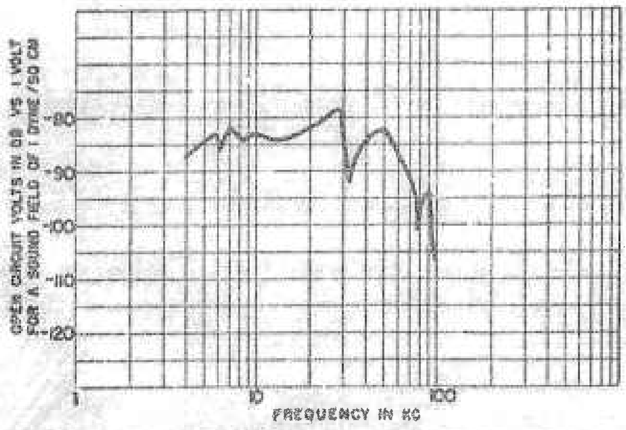


FIGURE 71. Receiving response, CFF 78187 projector. Water temperature = 78.5 F. Calculated threshold at 22 to 26 kc = —98 db vs 1 dyne/sq cm.

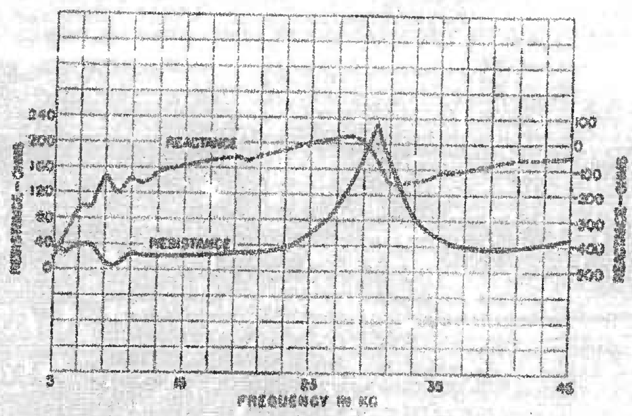


FIGURE 72. Impedance, CFF 78187 projector.

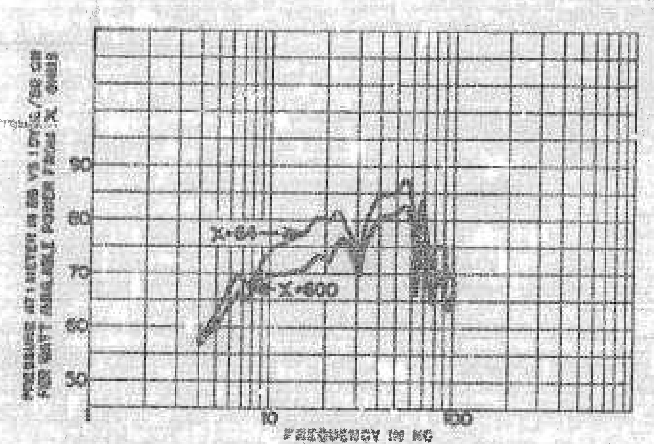


FIGURE 70. Transmitting response, CFF 78187 projector. Water temperature = 78.5 F.

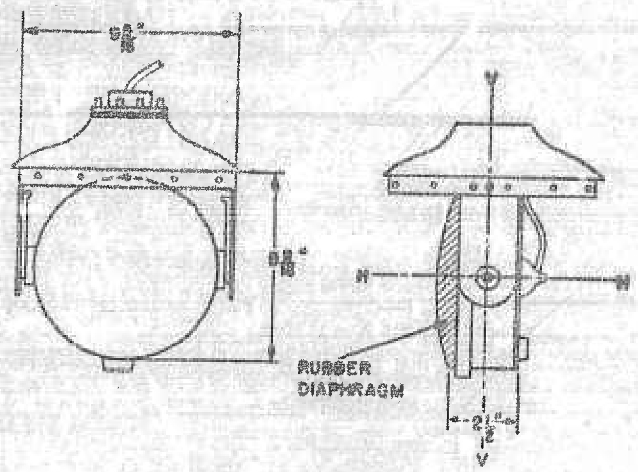


FIGURE 73. CFF 78187 projector.

2.7.19 QCA (QCB) Sonar-Ranging Projector (CBM 78017)

Type: Magnetostriction.

Manufacturer: Submarine Signal Company, Type 550C.

Reference: NDRC Report No. 6.1-sr1130-1194, December 28, 1943.[93]
USRL Orlando Project No. 187, January 1945.

Application: The CBM 78017 projector is used as a major unit in QC-1, QC-1A, in QCA, QCA-1, and in QCB, QCB-1, QCB-2, QCB-3 sonar equipment. These equipments are used on destroyers and on other large A/S ships for echo ranging on distant objects and for telegraphic communication between vessels similarly equipped.

The projector is mounted in a sea chest on a tubular shaft. An electrically operated hoist permits the projector to be lowered and trained in a horizontal direction while the system is in use and to be withdrawn into the sea chest at other times.

Description: The CBM 78017 projector is a magnetostrictive-type unit in a spherical housing. The active elements are nickel tubes which have one end imbedded in a steel plate serving as the diaphragm. A coil surrounding each nickel tube carries both the d-c polarizing current and pulses of the 24-kc operating current supplied by the driver unit. The projector is not split for BDI operation. The diaphragm is covered by a hemispherical shell of stainless steel, and the cavity is filled with a mixture of ethylene glycol and water. Weight of projector: 375 lb.

Efficiency at 25 kc: —14.5 db vs ideal.

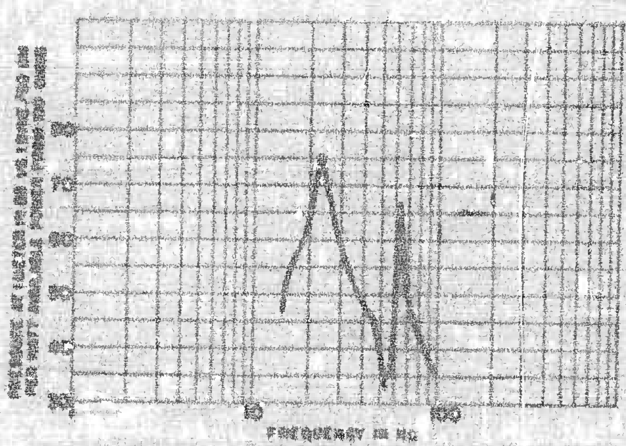


FIGURE 74. Transmitting response, CBM 78017 projector. Water temperature = 60 F. Q = 11.5.

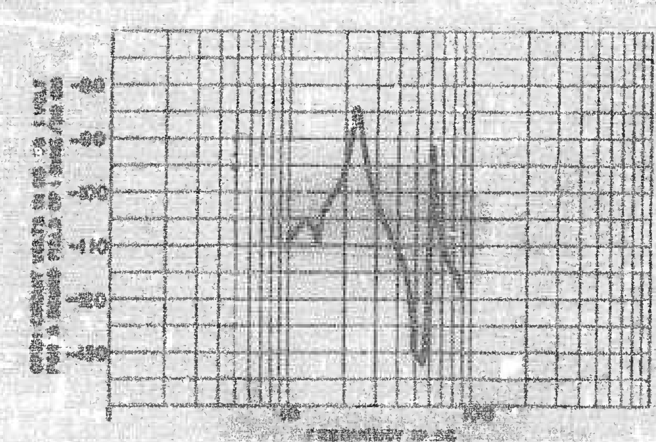


FIGURE 75. Receiving response, CBM 78017 projector. Water temperature = [illegible] F. Q = 10.5. Calculated threshold at [illegible] kc = —91.5 db vs 1 dyne/sq cm.

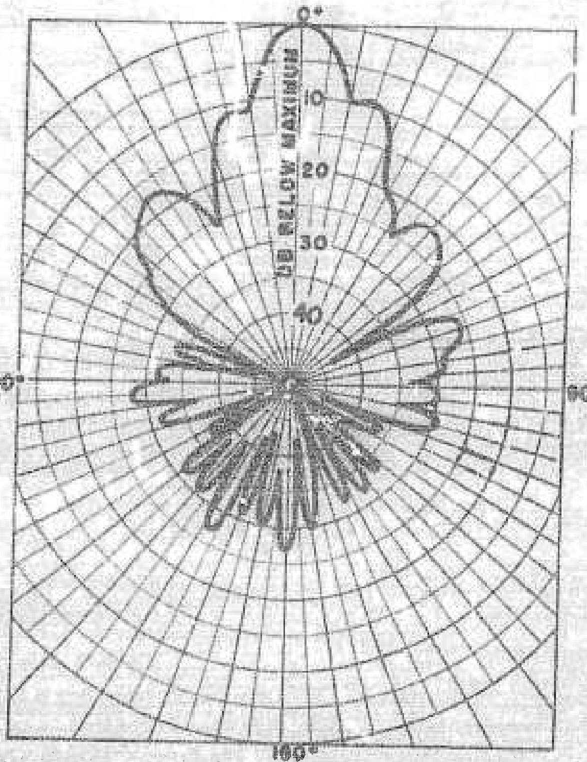


FIGURE 76. Directivity pattern, CBM 78017 projector at 22.5 kc. Directivity index = —21.9 db.

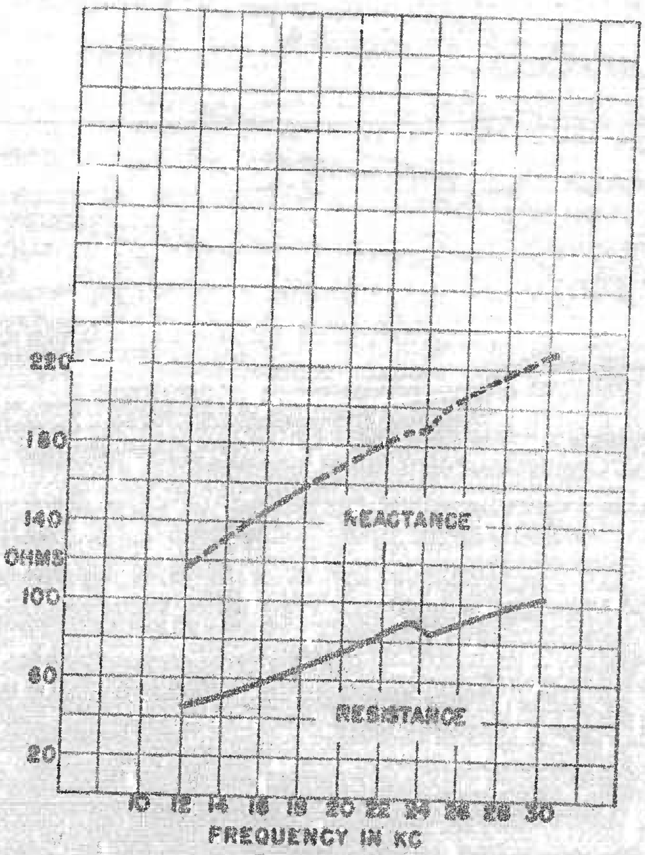


FIGURE 77. Impedance, CBM 78017 projector.

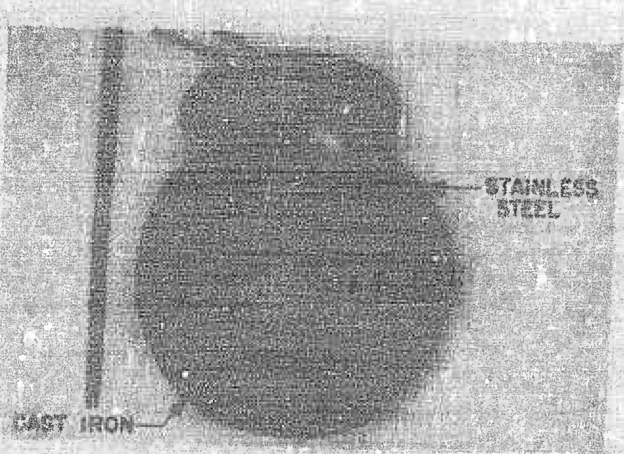


FIGURE 78A. CBM 78017 projector.

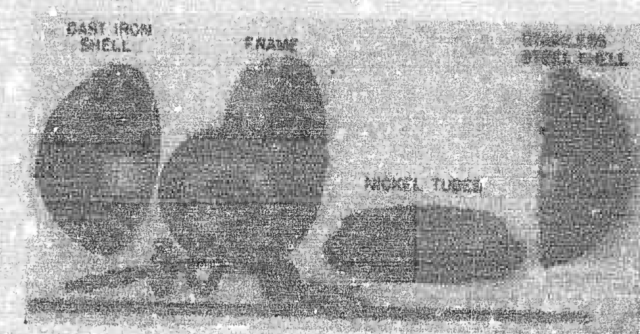


FIGURE 78B. CBM 78017 projector, component parts.

4

3.7.20 QCJ Sonar-Ranging Projector (CBM 78099)

Type: Magnetostriction.

Manufacturer: Submarine Signal Company, Type No. 550L.

Reference: BTL Reports of March 18, 23, 27, 1942.[40, 41, 42]

Application: The CBM 78099 projector is used in the QCJ-3, QCJ-4, QCJ-5, and QCJ-6 echo-ranging equipments for large A/S ships. It operates at a frequency of 24 kc and is mounted on the starboard side of the ship. A similar type projector, the CBM 78098, operating at a frequency of 20 kc, is mounted on the port side of the ship as a major unit in the QCL equipment.

Description: The CBM 78099 projector is a magnetostrictive type in a 19-in. spherical housing. The active elements are a number of nickel tubes which have one end imbedded in a steel plate serving as the diaphragm. A coil over each tube carries d-c polarizing current and the pulses of 24-kc driving current. The unit is not arranged for BDI. A hemispherical steel cover fastens over the diaphragm, and the cavity is filled with a mixture of ethylene glycol and water.

Impedance at resonance (tuned): $148 + j5.5$ ohms.

Efficiency at resonance: —11 db vs ideal.

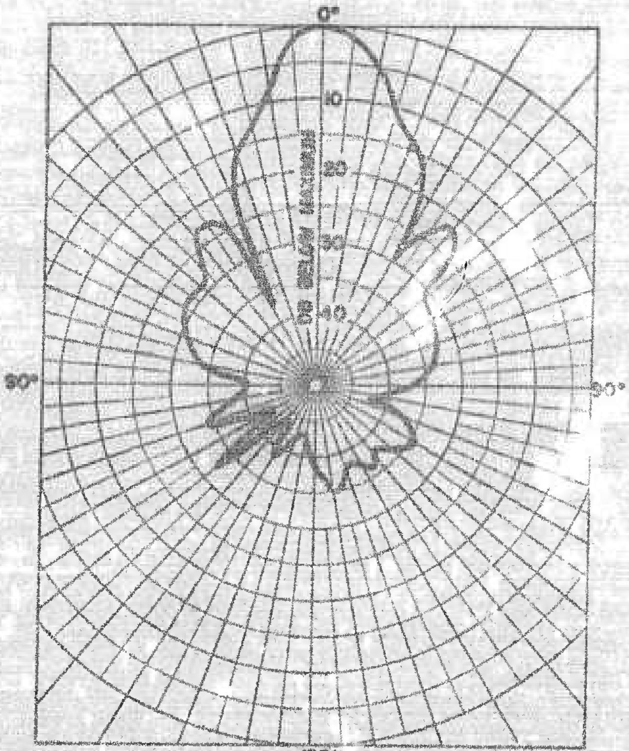


FIGURE 79. Directivity pattern, CBM 78099 projector at 23.5 kc. Directivity index = —22.1 db.

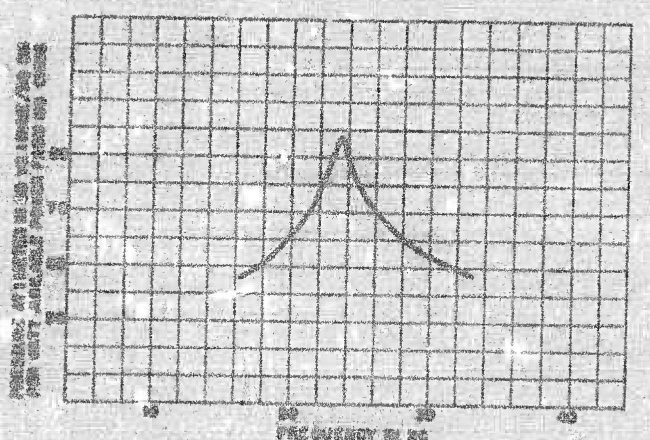


FIGURE 80. Tuned transmitting response, CBM 78099 projector. Water temperature = 62 F. Q = 25.

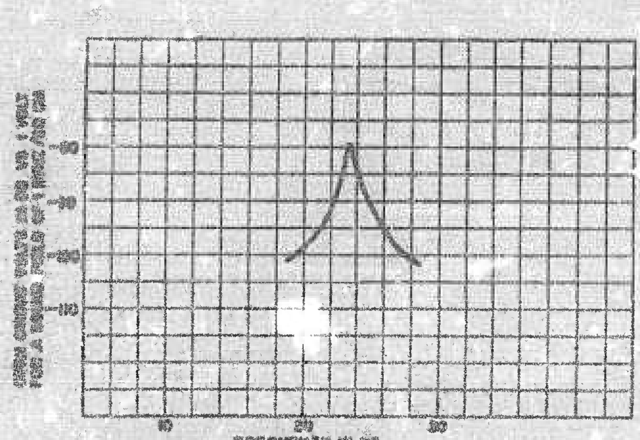


FIGURE 81. Tuned receiving response, CBM 78099 projector. Water temperature = 62 F. Q = 25. Calculated threshold at 23.5 kc = —94 db vs 1 dyne/sq cm.

2.7.21

QCJ-9 Sonar-Ranging Projector (CBM 78183)

Type: Magnetostriction.

Manufacturer: Submarine Signal Company, Type No. 550W.

Reference: NDRC Report No. 6.1-sr1130-1196, January 4, 1944.[38]
USRL Orlando Project No. 137, January 1945.

Application: The CBM 78183 projector is a major unit in the QCJ-9 sonar equipment used on large A/S ships for echo ranging on distant objects. The unit operates at 24 kc. It is used without a dome.

Description: This projector is a magnetostrictive-type unit in a spherical housing approximately 19 in. in diameter. The active elements are a group of nickel tubes attached at one end to a circular steel plate serving as the diaphragm. The nickel tubes are polarized by a d-c field and vibrate under the influence of a 24-kc field supplied by the driver for transmitting acoustic pulses into the water. The unit functions also as a receiver to convert acoustic pulse echoes to electric energy.

A hemispherical stainless steel cover fastens over the diaphragm and the cavity between the diaphragm and cover is filled with a 50 per cent solution of ethylene glycol and water.

A filter junction box, through which the d-c polarizing current of approximately 7 amp is supplied, is included as an integral part of the projector in these data.

Efficiency at resonance (24 kc): —19 db vs ideal.

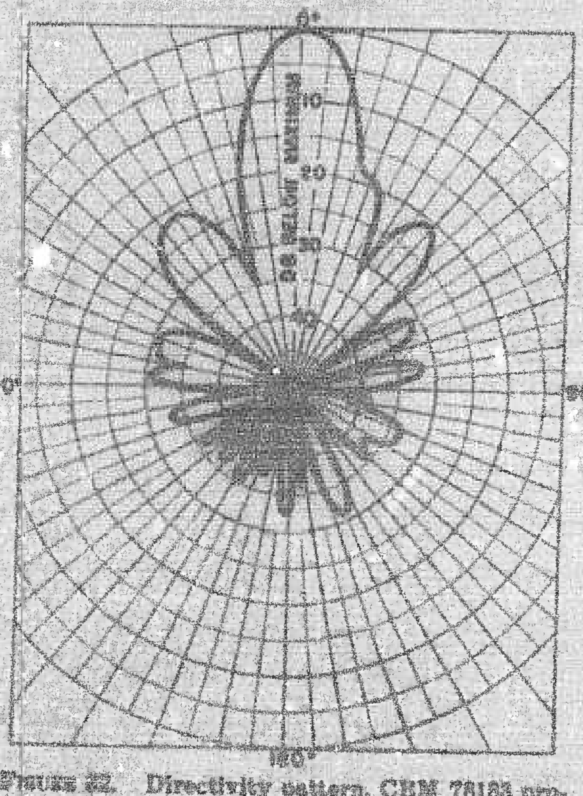


FIGURE 82. Directivity pattern, CBM 78183 projector at 24.4 kc. Directivity index = —22.9 db.

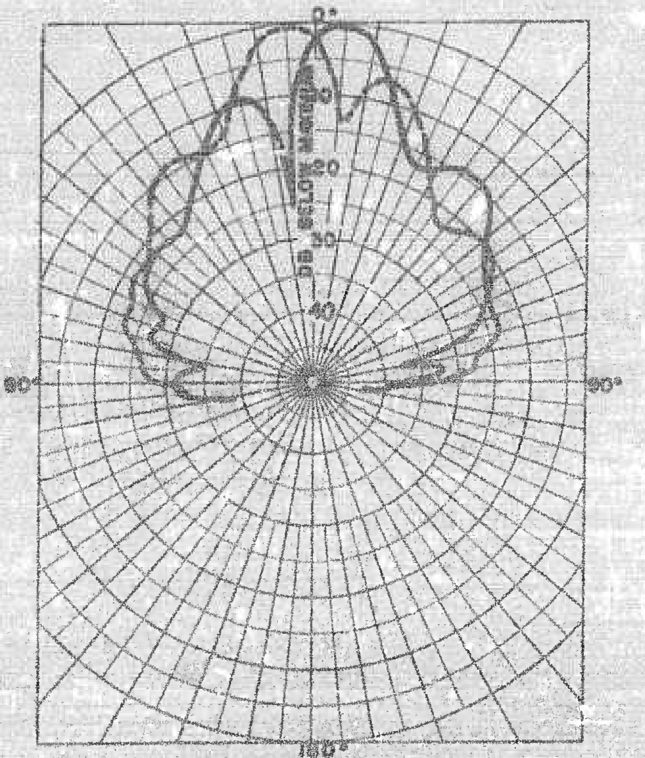


FIGURE 83. BDI patterns, CBM 78183 projector at 24.4 kc. Electrical phase shift = 80°.

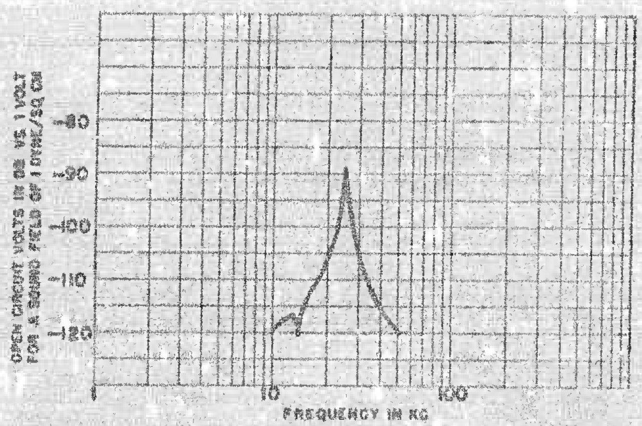


FIGURE 85. Receiving response, CBM 78183 projector. Water temperature = 61 F. Q = 22.5. Calculated threshold at 24.4 kc = −86 db vs 1 dyne/sq cm.

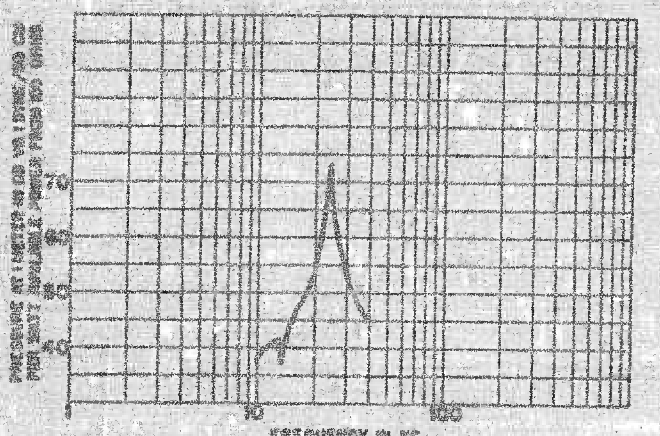


FIGURE 84. Transmitting response, CBM 78183 projector. Water temperature = 61 F. Q = 29.5.

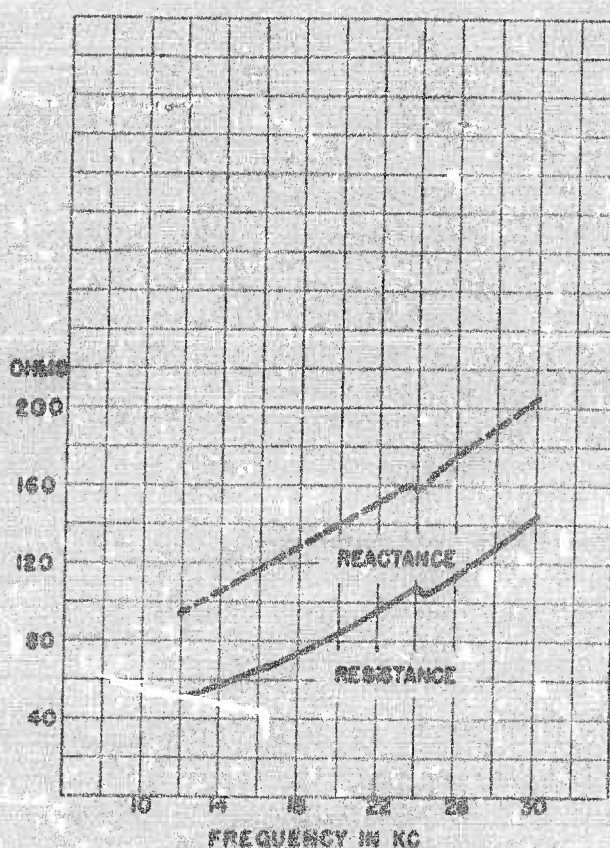


FIGURE 86. Impedance, CBM 78183 projector.

3.7.22 QCL Sonar-Ranging Projector (CRV 78103)

Type: Magnetostriction.

Manufacturer: Radio Corporation of America. Type No. MI 8943-2.

Reference: BTL Reports of March 18, 23, 27, 1942.[40, 41, 42]

Application: This projector is a major unit in QCL and QCL-7 sonar equipments used on large A/S vessels for echo ranging on distant objects. Early models of this projector were not arranged for BDI. This unit operates at 20 kc.

A similar type projector with a nominal operating frequency of 24 kc is coded CRV 78104 (MI 8943-1) and is used in QCJ-2 and QCJ-3 equipments. When both the QCL and the QCJ equipments are installed on the same vessel, the QCL (20 kc) equipment is normally installed on the port side and the QCJ (24 kc) equipment on the starboard side.

Description: The CRV 78103 projector is a magnetostriction unit in a spherical housing. A heavy steel plate mounted in the housing serves as the diaphragm. Imbedded in this plate are 319 nickel tubes which act as the driving elements. In this unit the nickel tubes and diaphragm are mechanically tuned to resonate at approximately 20 kc. The coil structure consists of a series-parallel arrangement of identical coils with one coil surrounding each tube. These coils carry both the d-c polarizing current (approximately 7 amp) and the high-frequency driving currents. The diaphragm is covered by a hemispherical shell of stainless steel, and the cavity is filled with an ethylene glycol solution. The back cover consists of a hemispherical shell of cast iron. The projector weighs approximately 490 lb.

A filter junction box having 0.01 μf across projector winding and 0.08 μf between each side projector winding and driving or receiving amplifier is included as an integral part of this projector in these data.

Impedance at 20.5 kc: $34 - j69.5$ ohms.

Efficiency at 20.5 kc: -10.1 db vs ideal.

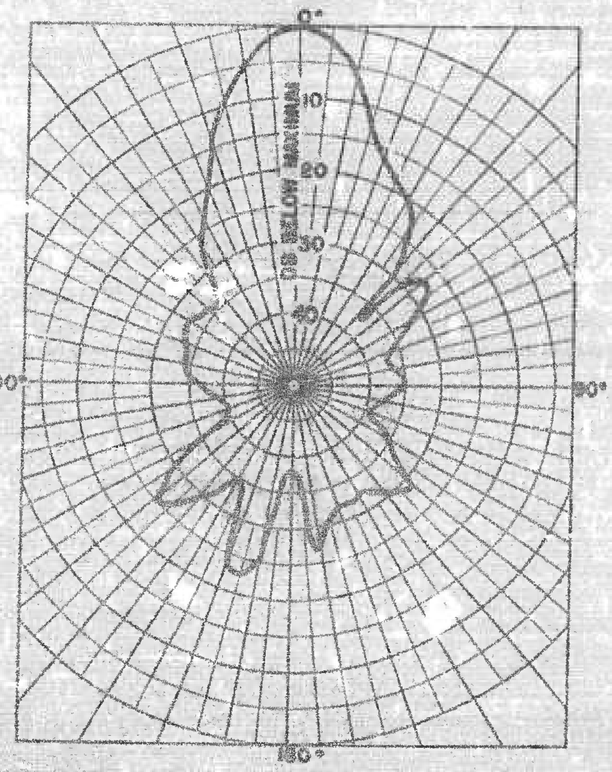


FIGURE 87. Directivity pattern, CRV 78103 projector at 20.5 kc. Directivity index = —21.4 db.

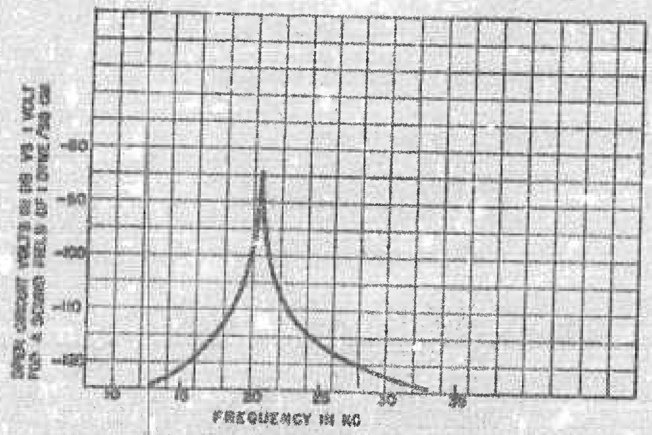


FIGURE 89. Receiving response, CRV 78103 projector including junction box. Water temperature = 62 F. Q = 100. Calculated threshold at 20.5 kc = —95 db vs 1 dyne/sq cm.

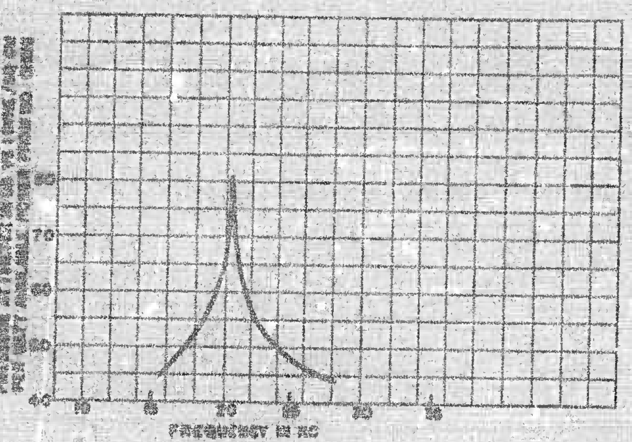


FIGURE 88. Transmitting response, CRV 78103 projector including junction box. Water temperature = 62 F. Q = 100.

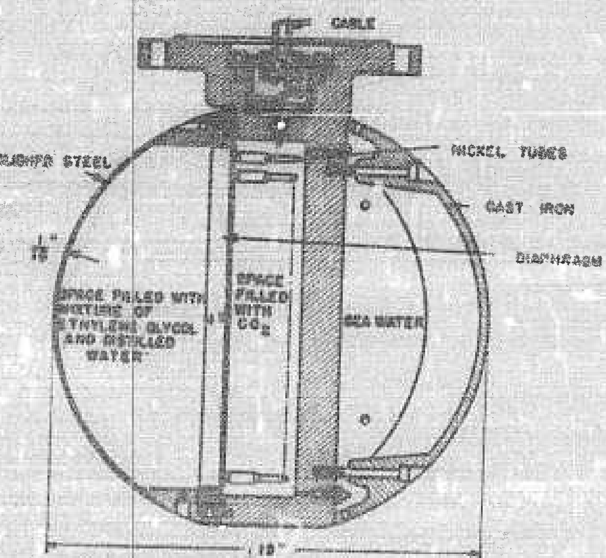


FIGURE 90. CRV 78103 projector.

2.7.33 QCL-8 Sonar-Ranging Projector (CBM 78182)

Type: Magnetostriction.

Manufacturer: Submarine Signal Company, Type No. 550V.

Reference: USRL Orlando Project No. 137, January 1945.

Application: The CBM 78182 projector is used in the QCL-8 echo-ranging equipment for large A/S ships. The projector is used without a dome.

Description: The CBM 78182 is a 19-in. diameter spherical-shaped magnetostriction transducer. The active elements consist of nickel tubes attached at one end to a circular steel plate serving as the diaphragm. The tubes are polarized by direct current flowing through coils surrounding them. A total magnetizing current of from 7 to 8 amp is required. These same coils carry the pulses of 20-kc energy supplied by the driver. The unit is diametrically tapered, that is, the tubes close to the vertical diameter are driven at higher amplitudes than those farther away. This projector is split for BDI operation; otherwise it is similar to the CBM 78098 (550M).

A hemispherical steel cover fastens over the diaphragm, and the cavity between diaphragm and cover is filled with a 50 per cent solution of ethylene glycol and water.

Efficiency at resonance: —19 db vs ideal.

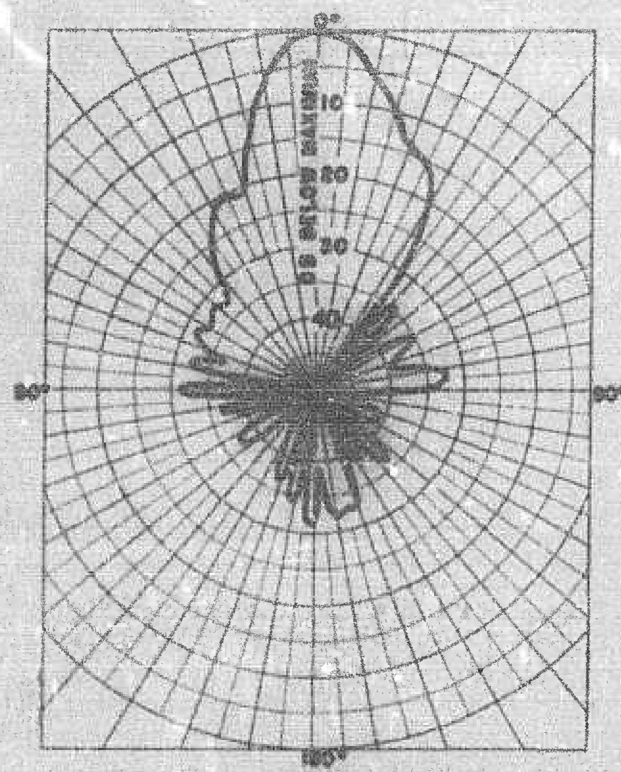


FIGURE 91. Directivity pattern, CBM 78182 projector at 20.5 kc. Connected parallel aiding. Directivity index = —21.2 db.

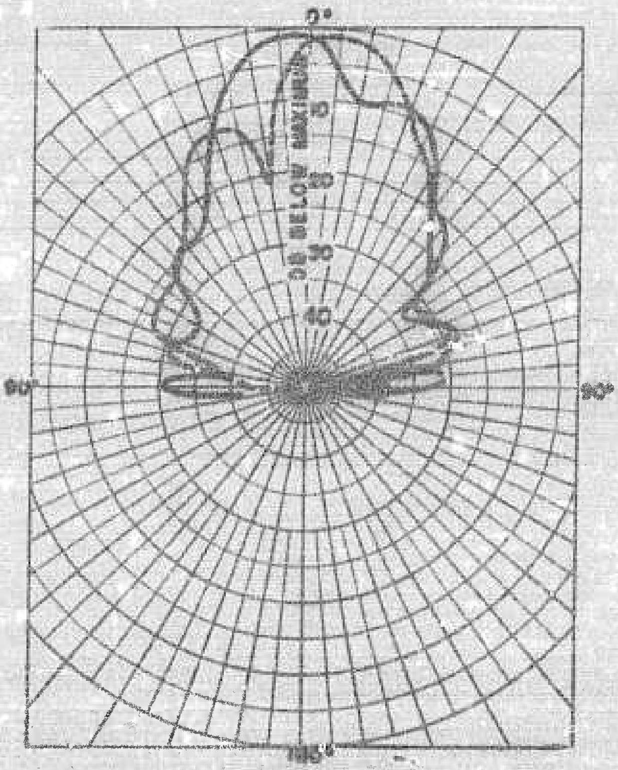


FIGURE 92. BDI patterns, CBM 78182 projector at 20.5 kc. Electrical phase shift = 68.5°.

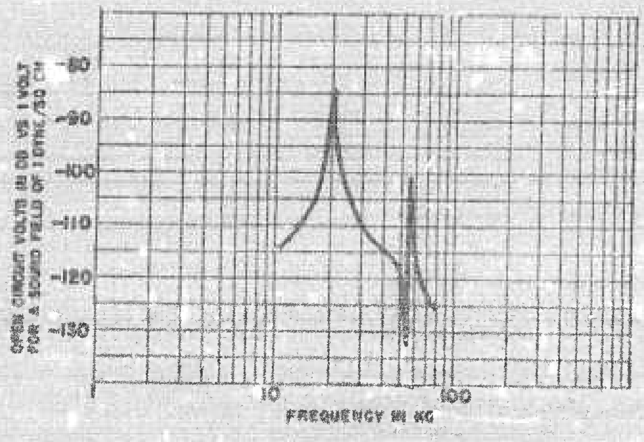


FIGURE 94. Receiving response, CBM 78182 projector. Connected parallel aiding. Water temperature = 61 F. Q = 25. Calculated threshold at 20.5 kc = —91.2 db vs 1 dyne/sq cm.

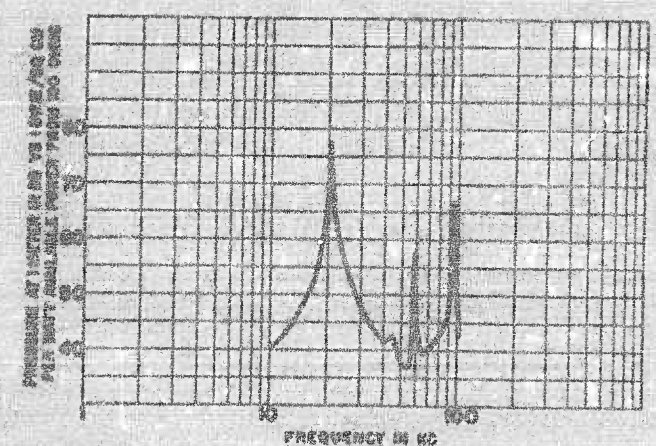


FIGURE 93. Transmitting response, CBM 78182 projector. Connected parallel aiding. Water temperature = 61 F. Q = 43.

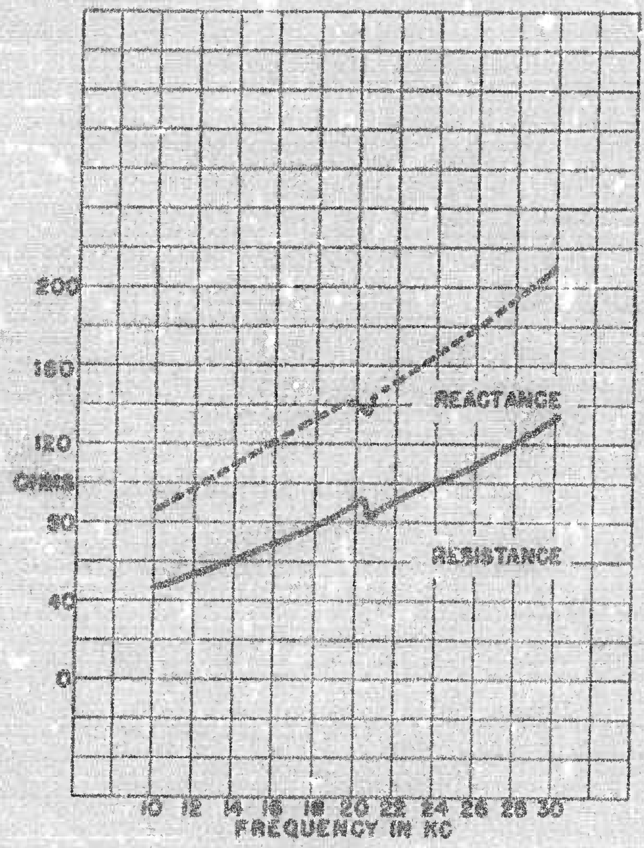


FIGURE 95. Impedance, CBM 78182 projector.

2.7.24

QCN Sonar-Ranging Projector (CBM 78115)

Type: Combination Magnetostriction and Rochelle Salt Crystal.
Manufacturer: Submarine Signal Company, Type No. 733F.
Reference: NDRC BTL Reports of March 18, 23, 27, 1942.[40, 41, 42]

Application: The CBM 78115 projector is a major unit in QCN-1, QCN-2, or QCN-3 sonar equipments. These equipments are used on large A/S ships for echo ranging on distant objects, telegraphic communication with other ships similarly equipped, and for listening to high-frequency sounds produced by other ships. This projector operates at 24 kc and is not arranged for BDI. When this type projector is arranged for BDI operation, it is coded CBM 78184 (733K) and is used in the QCN-4 equipment.

A similar type projector with a nominal operating frequency of 20 kc is coded CBM 78116 (733G) and is used in QCO, QCO-1, or QCO-2 equipments. When arranged for BDI this unit is coded CBM 78185 (733L) and is used in the QCO-3 equipment. When both 20-kc and 24-kc equipments are installed on the same ship, the QCN (24 kc) equipment is normally installed on the starboard side and the QCO (20 kc) equipment on the port side.

Description: The CBM 78115 projector is a combination magnetostriction unit and a Rochelle salt crystal unit in a spherical housing.

The magnetostriction unit or QC face consists of a group of nickel tubes which are attached at one end to the circular steel plate serving as the diaphragm. The nickel tubes are polarized by a d-c field and vibrate under the influence of an a-c field supplied by the driver for transmitting acoustic pulses into the water. The unit functions also as a receiver to convert the acoustic pulse echoes returned from distant objects in the water into electric energy. The diaphragm is covered by a hemispherical shell of stainless steel, and the cavity is filled with a 50 per cent mixture of ethylene glycol and water.

A filter junction box having 0.01 μf across projector and 0.06 μf between each side projector winding and driving or receiving amplifier is included as an integral part of the QC unit in these data.

The Rochelle salt crystal unit or JK face is used for listening to high-frequency noises generated by propellers and other moving parts of distant vessels. This unit consists of a number of blocks of Rochelle salt crystals mounted on a heavy steel back plate. A hemispherical rubber shell encloses the unit, and the cavity between the crystal blocks and the rubber shell is filled with technical castor oil. Weight of projector: 560 lb.

Impedance: QC face at 24 kc: $168 + j48$ ohms.
JK face at 35 kc: $630 - j1120$ ohms.

Efficiency: QC face at resonance (24 kc): —15 db vs ideal.
JK face at 25 kc: —1.6 db vs ideal.

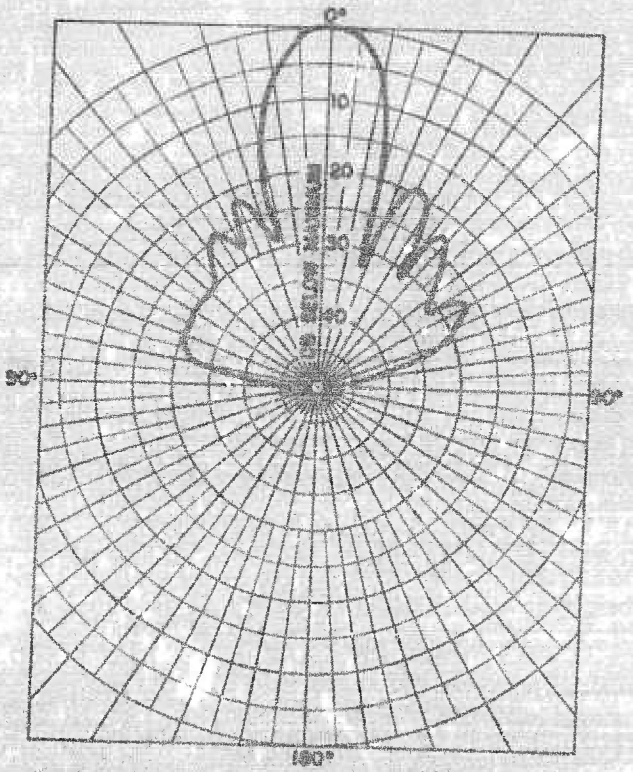


FIGURE 96. Directivity pattern, CBM 78115 projector at 23.8 kc. M/S unit, including junction box. Directivity index = —22.4 db.

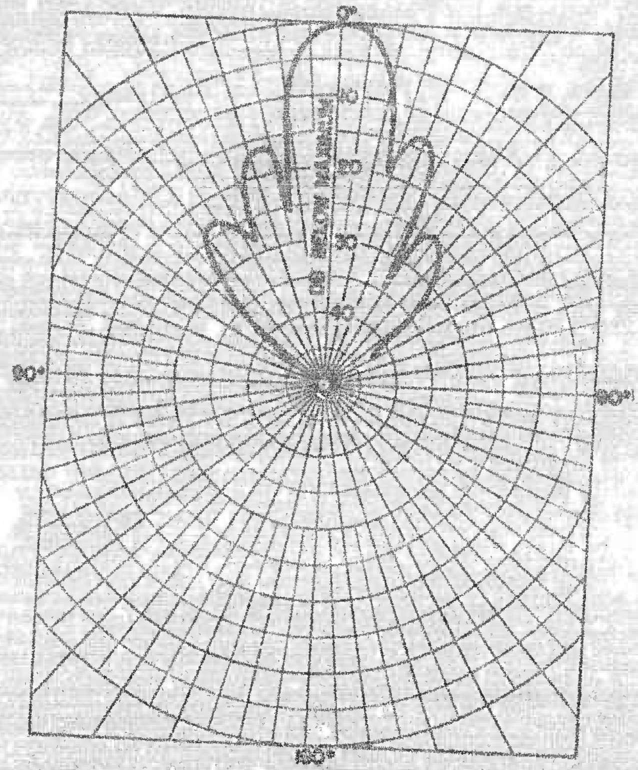


FIGURE 97. Directivity pattern, CBM 78115 projector at 25 kc. R/S unit. Directivity index = —23.1 db.

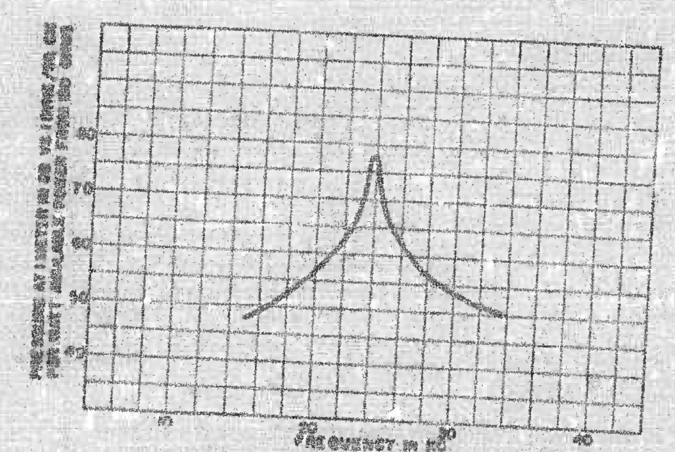


FIGURE 98. Transmitting response, CBM 78115 projector. M/S unit, including junction box. Water temperature = 62 F. Q = 35.

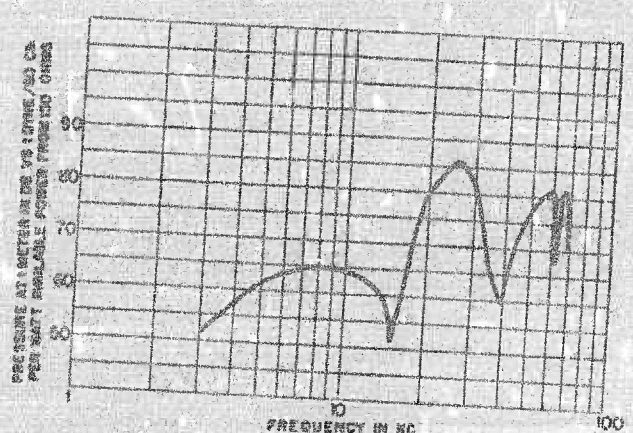


FIGURE 99. Transmitting response, CBM 78115 projector. R/S unit. Water temperature = 62 F.

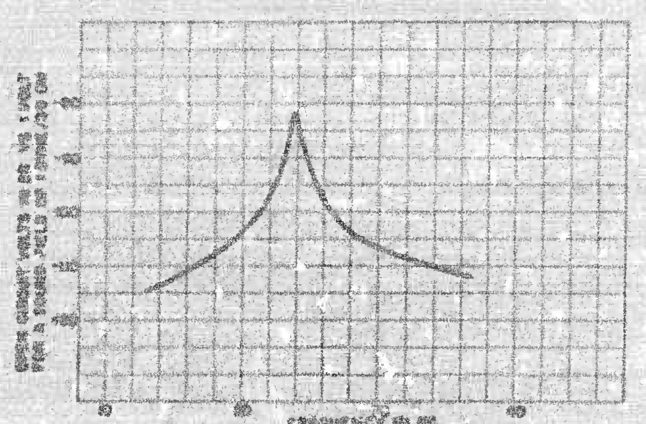


FIGURE 100. Receiving response, CBM 78115 projector. M/S unit, including junction box. Water temperature = 62 F, Q = 36.

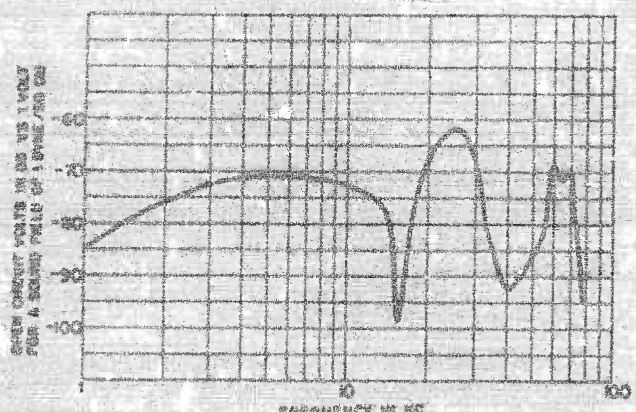


FIGURE 101. Receiving response, CBM 78115 projector. R/S unit. Water temperature = 62 F.

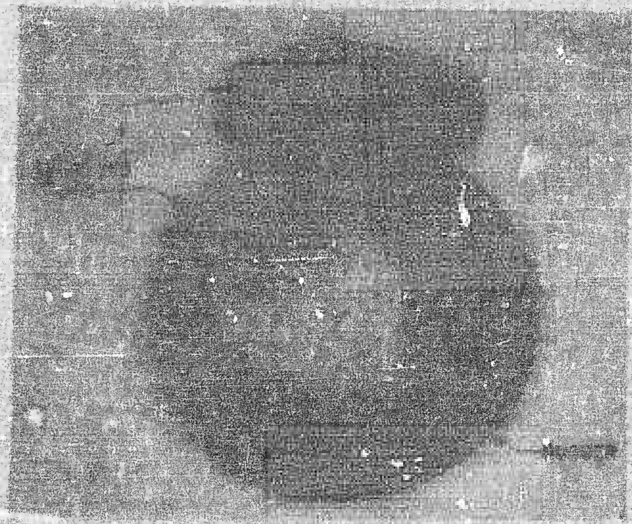


FIGURE 102A. CBM 78115 projector.

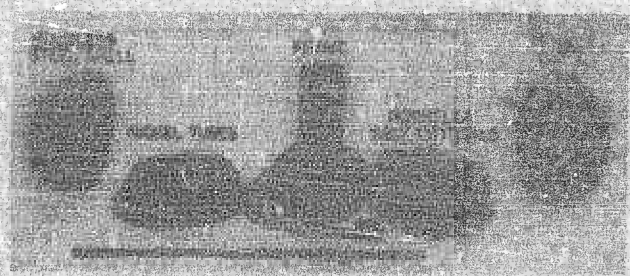


FIGURE 102B. CBM 78115 projector, component parts.

2.7.23

QCN-4 Sonar-Ranging Projector (CBM 78184)

Type: Combination Magnetostriction and Rochelle Salt Crystal.

Manufacturer: Submarine Signal Company, Type No. 733K.

Reference: USRL Orlando Project No. 137, January 1945.

Application: The CBM 78184 projector is a combination echo-ranging and listening unit. It is a major unit in the QCN-4 sonar equipment for large A/S ships.

Description: The CBM 78184 projector is a combination magnetostriction unit and a Rochelle salt unit in a 19-in. diameter spherical housing.

The magnetostriction unit consists of a group of nickel tubes which are attached at one end to the circular steel plate serving as the diaphragm. The nickel tubes are polarized by a d-c field and vibrate under the influence of 24-kc a-c field supplied by the driver for transmitting acoustic pulses into the water. The unit functions also as a receiver to convert acoustic echoes into electric energy. The diaphragm is covered by a hemispherical shell of stainless steel, and the cavity is filled with a 50 per cent mixture of ethylene glycol and water. The unit is split for BDI operation. Otherwise this projector is similar to the CBM 78115 (733F) projector.

The Rochelle salt crystal unit is used for listening to high-frequency noises generated by propellers and other moving parts of distant vessels. This unit consists of a number of blocks of Rochelle salt crystals mounted on a heavy steel backing plate. A hemispherical rubber shell encloses the unit and the cavity between the crystal blocks and the rubber shell is filled with technical castor oil.

Efficiency: M/S unit (24 kc) : —11 db vs ideal.
R/S unit (24 kc) : —3.5 db vs ideal.

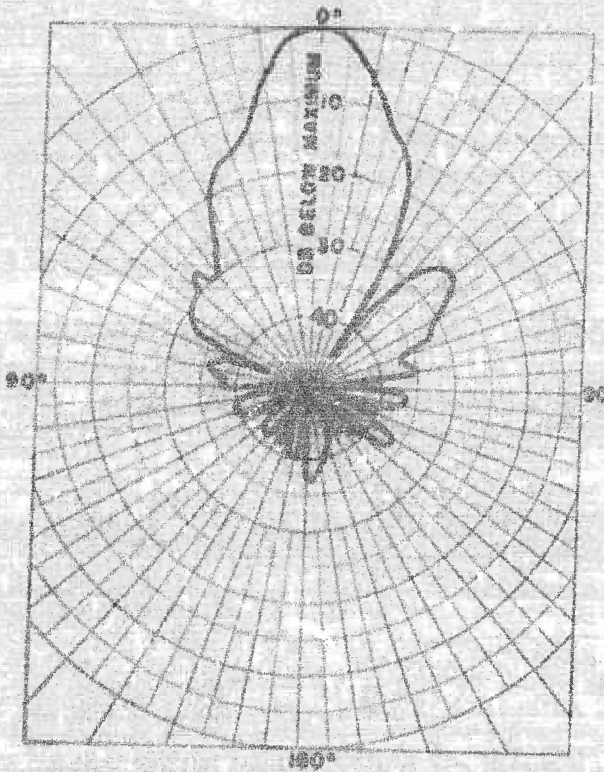


FIGURE 103. Directivity pattern, CBM 78184 projector at 24 kc. M/S unit. Connected parallel aiding. Directivity index = —21.7 db.

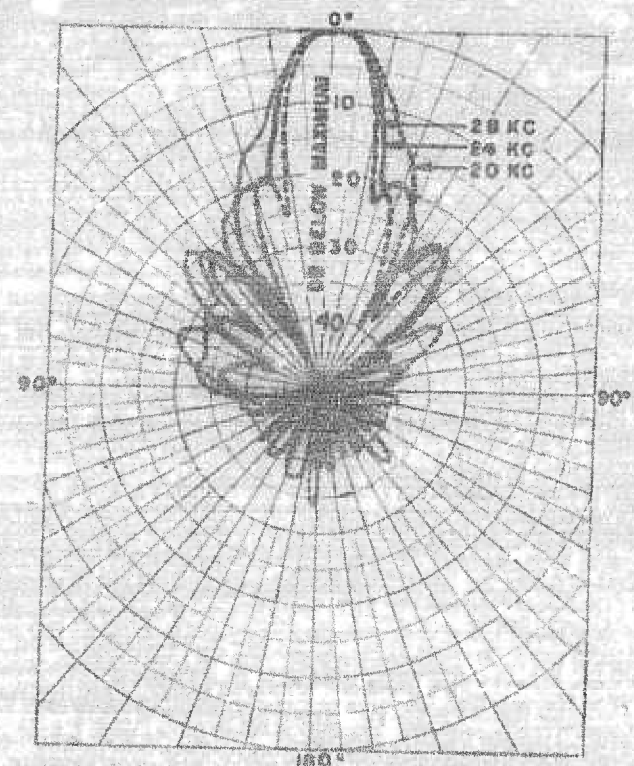


FIGURE 104. Directivity patterns, CBM 78184 projector. R/S unit. Directivity index at 20 kc = —22.0 db, at 24 kc = —23.6 db, at 28 kc = —25.0 db.

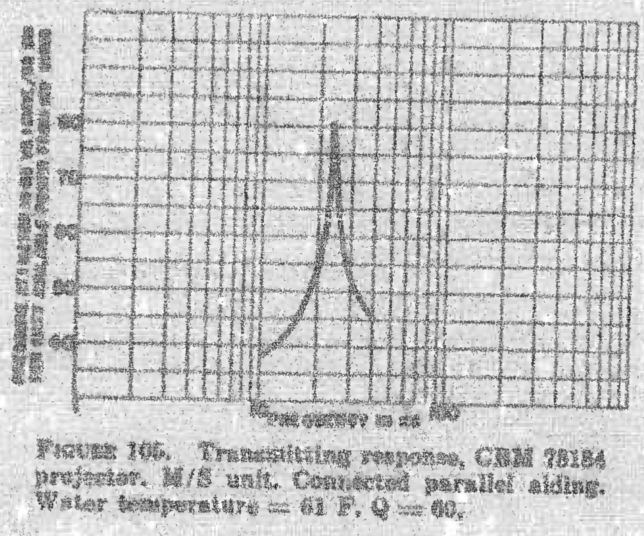


FIGURE 105. Transmitting response, CBM 78184 projector. M/S unit. Connected parallel aiding. Water temperature = 61 F, Q = 60.

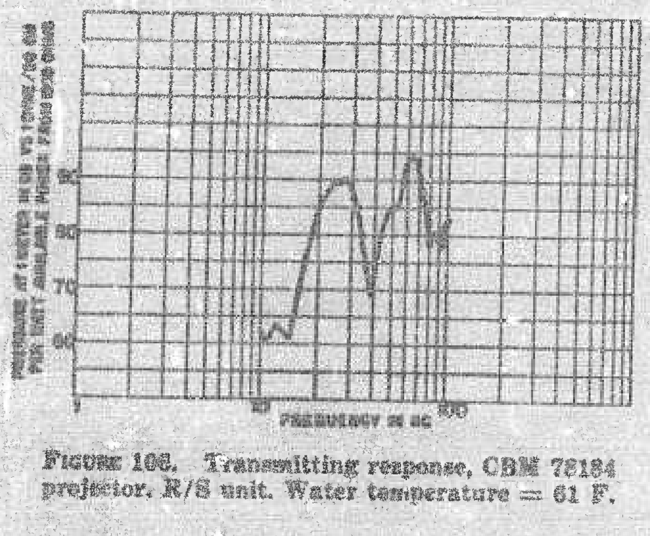


FIGURE 106. Transmitting response, CBM 78184 projector. R/S unit. Water temperature = 61 F.

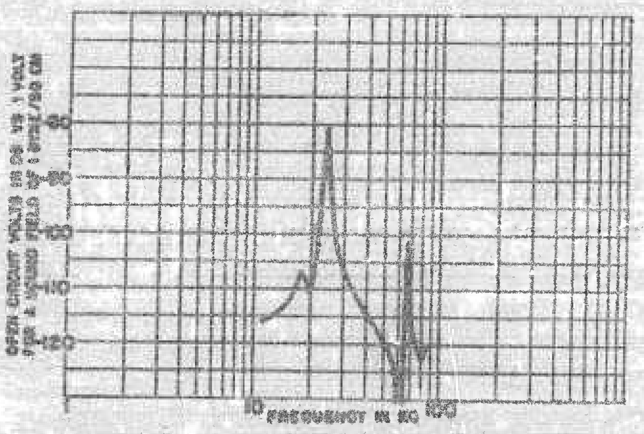


FIGURE 107. Receiving response, CBM 78184 projector. M/S unit. Connected parallel aiding. Water temperature = 61 F. Q = 55. Calculated threshold at 24 kc = —94.4 db vs 1 dyne/sq cm.

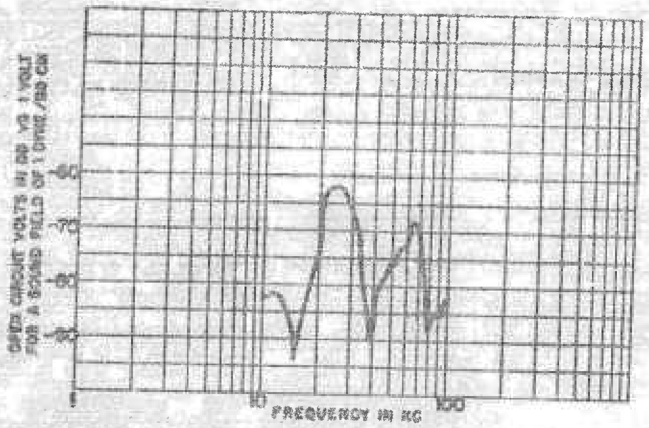


FIGURE 108. Receiving response, CBM 78184 projector. R/S unit. Water temperature = 61 F. Calculated threshold at 24 kc = —103.8 db vs 1 dyne/sq cm.

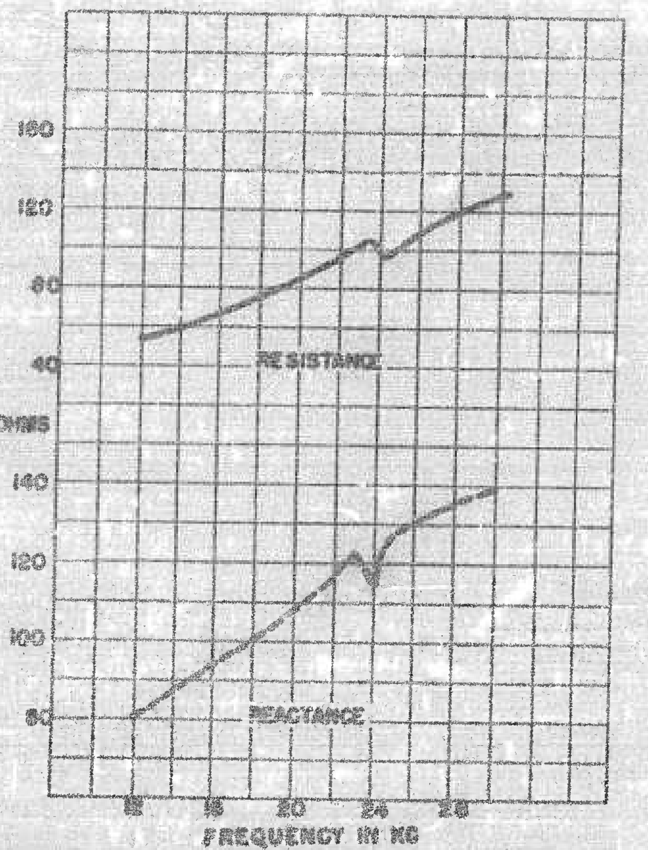


FIGURE 109. Impedance, CBM 78184 projector. M/S unit.

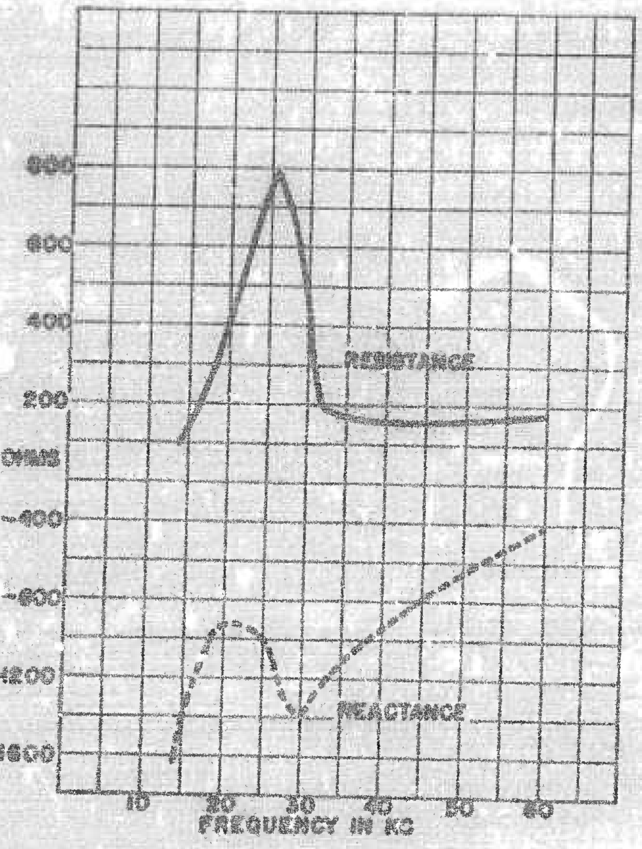


FIGURE 110. Impedance, CBM 78184 projector. R/S unit.

2.7.26 QCO-3 Sonar-Ranging Projector (CBM 78185)

Type: Combination Magnetostriction and Rochelle Salt Crystal.
Manufacturer: Submarine Signal Company, Type No. 733L.
Reference: NDRC Report No. 6.1-sr1130-1368, March 6, 1944.[96]
USRL Orlando Project No. 137, January 1945.

Application: The CBM 78185 projector is a combination echo-ranging and listening unit. It is a major unit in the QCO-3 sonar equipment for large A/S ships.

Description: The CBM 78185 projector is a combination of a magnetostriction unit and a Rochelle salt unit mounted back to back in a 19-in. diameter spherical housing.

The M/S unit operates at approximately 20 kc. It is similar to the QCO, QCO-1, QCO-2 projector CBM 78116 (733G), with the exception that it is parallel-split for BDI operation. It is also similar to the CBM 78184 (733K) projector used in the QCN-4 equipment, except that the latter unit is designed to operate at 24 kc.

Efficiency at resonance: M/S unit: —17 db vs ideal.
R/S unit: See Section 2.7.25.

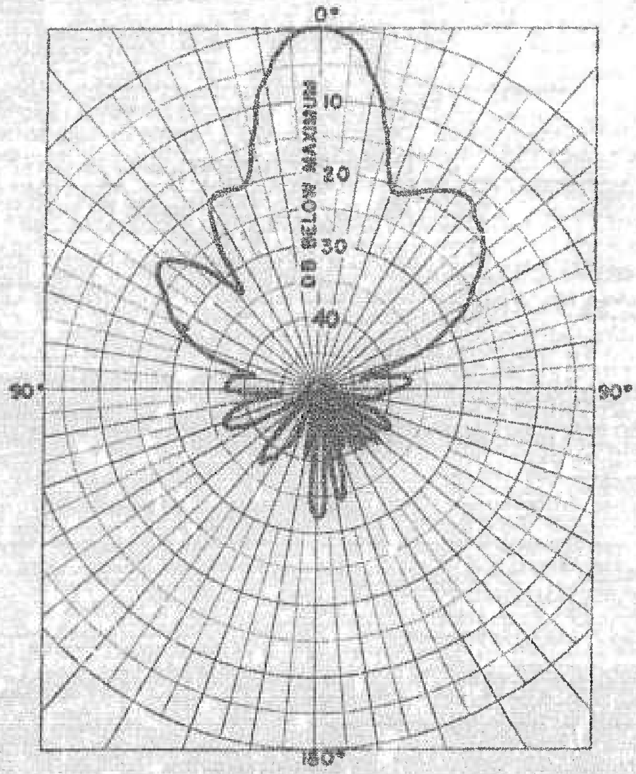


FIGURE 111. Directivity pattern, CBM 78185 projector at 20.7 kc. M/S unit. Directivity index = —21.2 db.

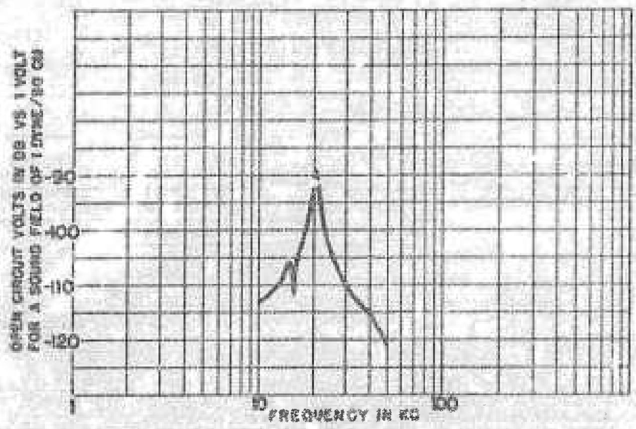


FIGURE 113. Receiving response, CBM 78185 projector. M/S unit. Connected parallel aiding. Water temperature = 61 F. Q = 14. Calculated threshold at 20.7 kc = —86 db vs 1 dyne/sq cm.

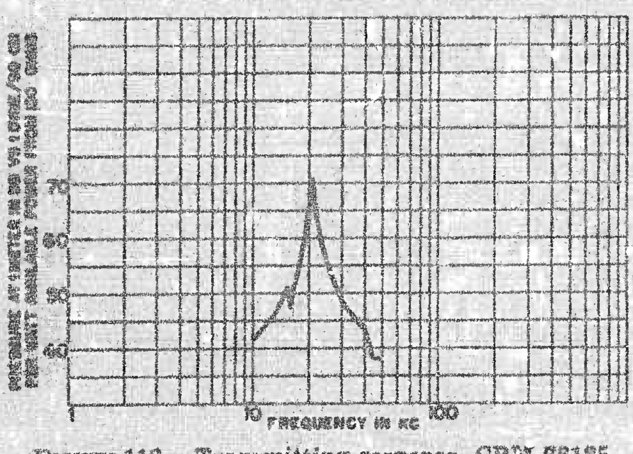


FIGURE 112. Transmitting response, CBM 78185 projector. M/S unit. Connected parallel aiding. Water temperature = 61 F. Q = 20.

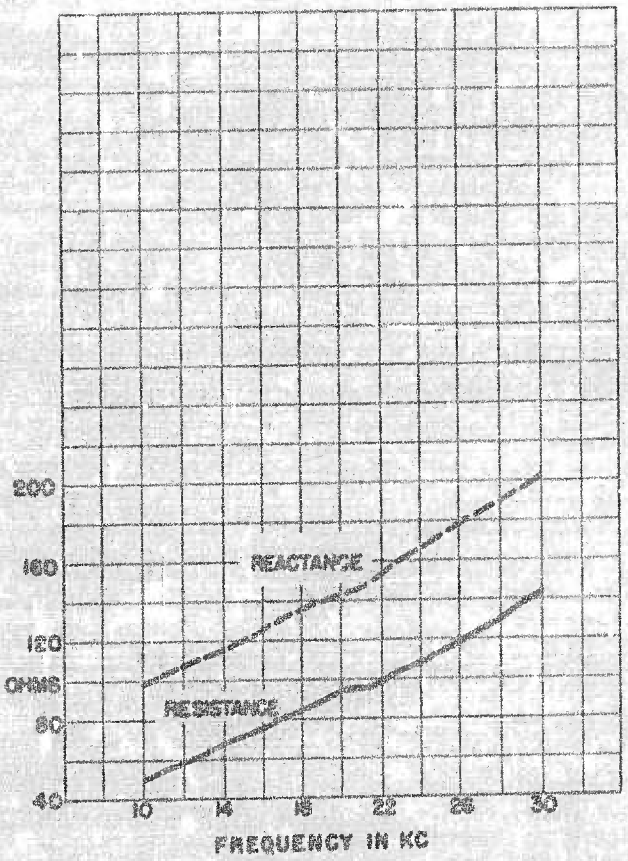


FIGURE 114. Impedance, CBM 78185 projector. M/S unit.

2.7.27

QCQ Sonar-Ranging Projector (CBM 78145)

Type: Magnetostriction.

Manufacturer: Submarine Signal Company, Type No. 880.

Reference: NDRC Report No. 6.1-sr20-887, July 6, 1943.[56]
NDRC Report No. 6.1-sr20-948, August 16, 1943.[57]

Application: The CBM 78145 projector is a major unit in the QCQ, QCQ-3 echo-ranging equipments for large A/S vessels. It operates at a frequency of 24 kc. A similar type unit, CBM 78146 (880A), which operates at a frequency of 20 kc, is a part of the QCR, QCR-2 equipment. The QCQ projector is normally mounted on the starboard side of the ship and the QCR projector on the port side.

Description: The CBM 78145 projector is a magnetostrictive type in a banjo-shaped housing 17 in. in diameter by 5⅛ in. deep. The vibrating element is a group of nickel tubes attached at one end to a circular steel plate serving as the diaphragm. A coil surrounding each tube carries the d-c polarizing current and the pulses of 24-kc alternating current supplied by the drive. The unit functions also to receive the echoes returned from any reflecting surface such as a distant submarine or vessel.

Impedance at 24.2 kc tuned: $90 - j34.4$ ohms.

Efficiency at resonance: -11 db vs ideal.

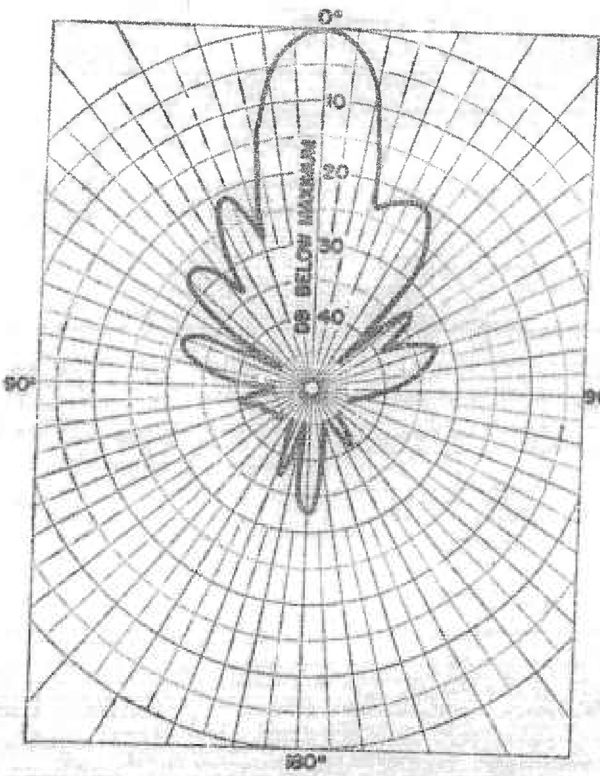


FIGURE 115. Directivity pattern, CBM 78145 projector at 24.2 kc. Directivity index = —22.9 db.

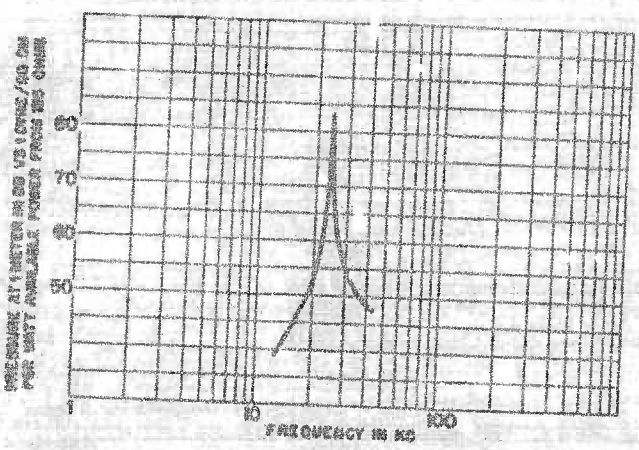


FIGURE 116. Transmitting response, CBM 78145 projector including junction box. Water temperature = 72 F.

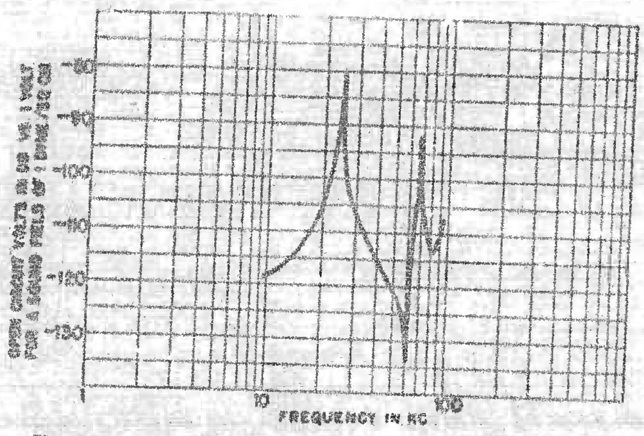


FIGURE 117. Receiving response, CBM 78145 projector including junction box. Water temperature = 72 F. Calculated threshold at 24.2 kc = —94 db vs 1 dyne/sq cm.

2.7.28

QCS-1 Sonar-Ranging Projector (CBM 78164A)

Type: Combination Magnetostriction and Rochelle Salt Crystal.

Manufacturer: Submarine Signal Company, Type No. 900E.

Reference: USRL Orlando Project No. 137, January 1945.

Application: This projector is a combination of two units in one housing, one unit being used for echo ranging on distant objects and for telegraphic communication with other vessels similarly equipped and a second unit for listening to propeller noise or other machinery noise on moving vessels. It forms a major unit in the QCS-1 equipments for large A/S ships.

Description: The CBM 78164A projector is banjo-shaped, 17 in. in diameter by 7⅝ in. deep. One face is the diaphragm of the magnetostriction unit for echo ranging, and the opposite face is the diaphragm of the Rochelle salt listening unit. The projector is used inside a retractable free-flooding type dome (8£2A).

The magnetostriction unit consists of a group of nickel tubes attached at one end to the steel plate serving as the diaphragm. The tubes are polarized by a d-c field and vibrate under the influence of a 24-kc alternating field supplied by the driver for transmitting acoustic pulses into the water. The unit functions also as a receiver to convert acoustic echoes into electric energy. The unit is parallel-split for BDI operation.

The Rochelle salt listening unit consists of a number of blocks of X-cut Rochelle salt crystals fastened to a steel backing plate. The cavity between the crystals and the diaphragm is filled with air-free castor oil.

The CBM 78164A (900E) projector is similar to the CBM 78165A (900D) projector used in the QCT-1 equipments, except that the M/S unit of the latter operates at 20 kc instead of 24 kc. When these types of projectors are not split for BDI operation, they are known as the CBM 78164 (900A) and the CBM 78165 (900) projectors. Weight of projector: 250 lb.

Efficiency: M/S unit at resonance: —18 db vs ideal.
R/S unit (24 kc): —5 db vs ideal.

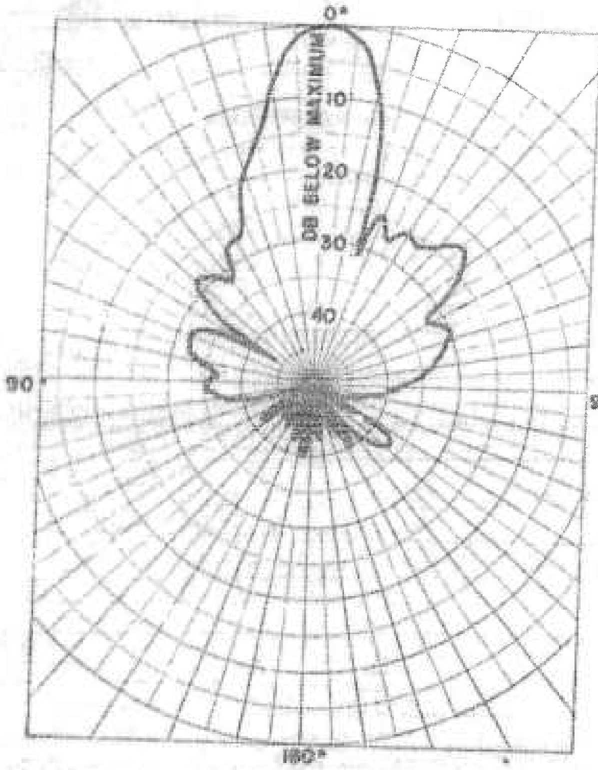


FIGURE 118. Directivity pattern, CBM 78164A projector at 24.2 kc. M/S unit. Connected parallel aiding. Directivity index = —23 db.

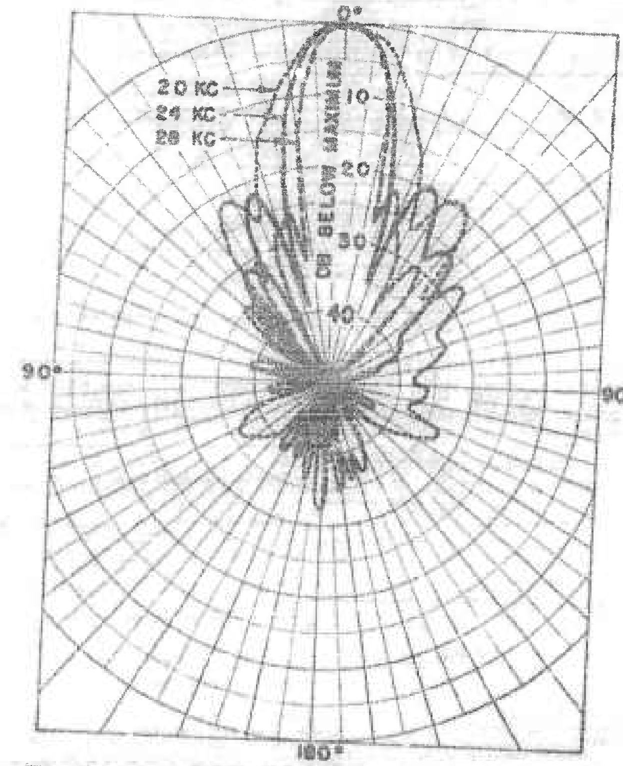


FIGURE 119. Directivity patterns, CBM 78164A projector. R/S unit. Directivity index: at 20 kc = —21.1 db, at 24 kc = —23.8 db, at 28 kc = —25.2 db.

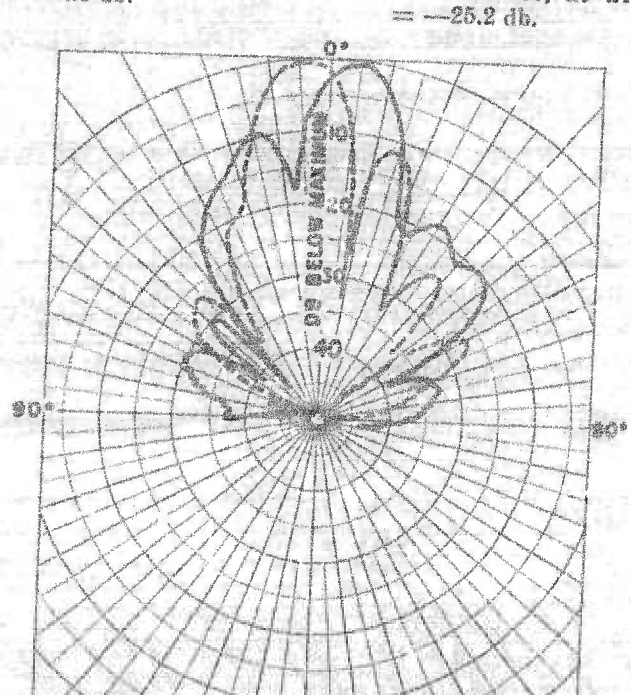


FIGURE 120. BDI patterns, CBM 78164A projector at 24.2 kc. M/S unit. Electrical phase shift = 67.5°.

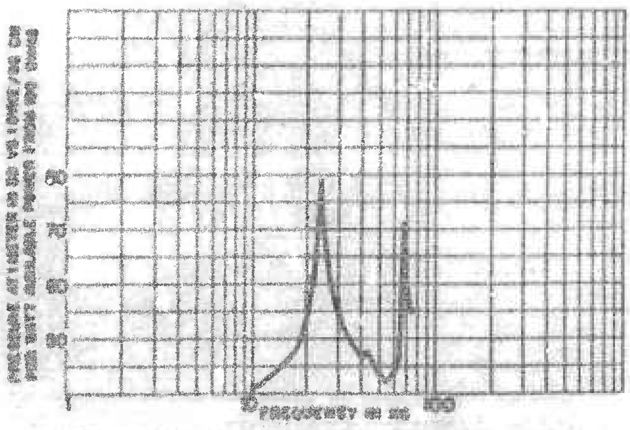


FIGURE 121. Transmitting response, CBM 78164A projector. M/S unit. Connected parallel aiding. Water temperature = 62 F. Q = 45.

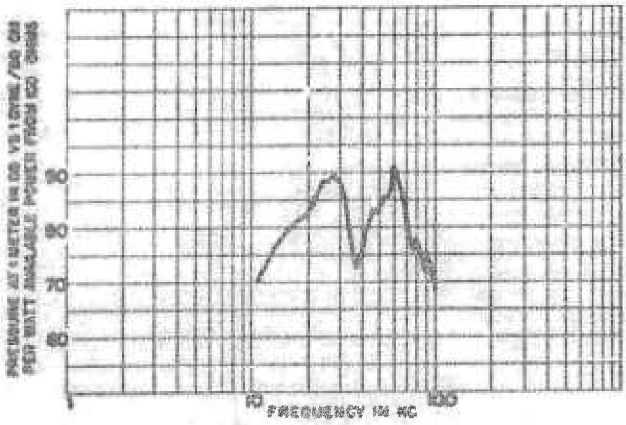


FIGURE 122. Transmitting response, CBM 78164A projector. R/S unit. Water temperature = 62 F.

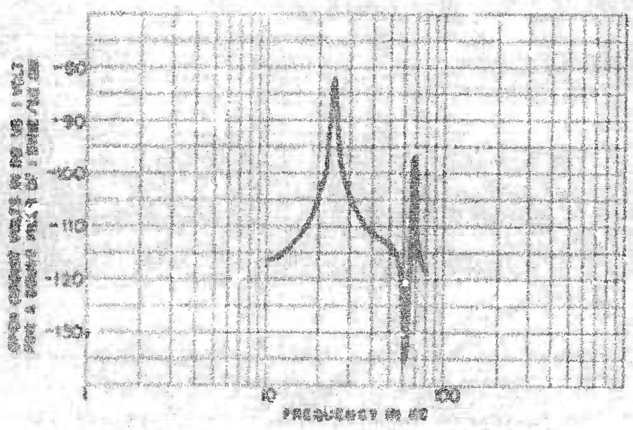


FIGURE 123. Receiving response, CBM 78164A projector. M/S unit. Connected parallel aiding. Water temperature = 62 F. Q = 36. Calculated threshold at 24.2 kc = —93.5 db vs 1 dyne/sq cm.

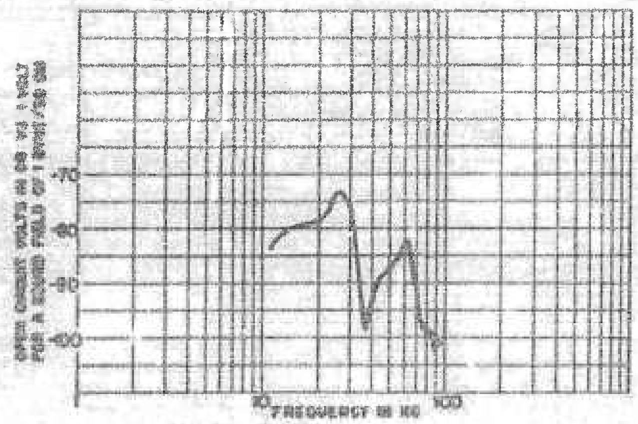


FIGURE 124. Receiving response, CBM 78164A projector. R/S unit. Water temperature = 62 F. Calculated threshold at 24 kc = —120.5 db vs 1 dyne/sq cm.

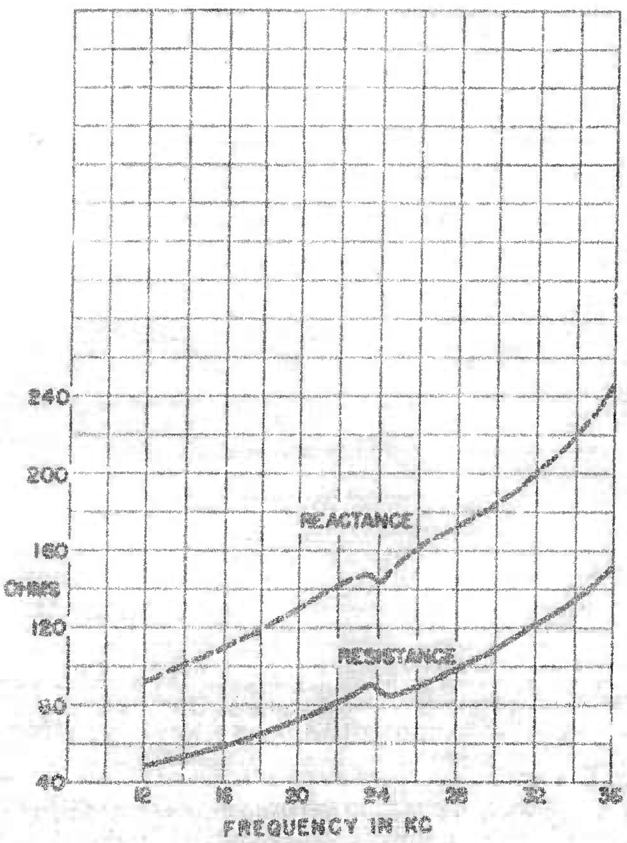


FIGURE 125. Impedance, CBM 78164A projector. M/S unit.

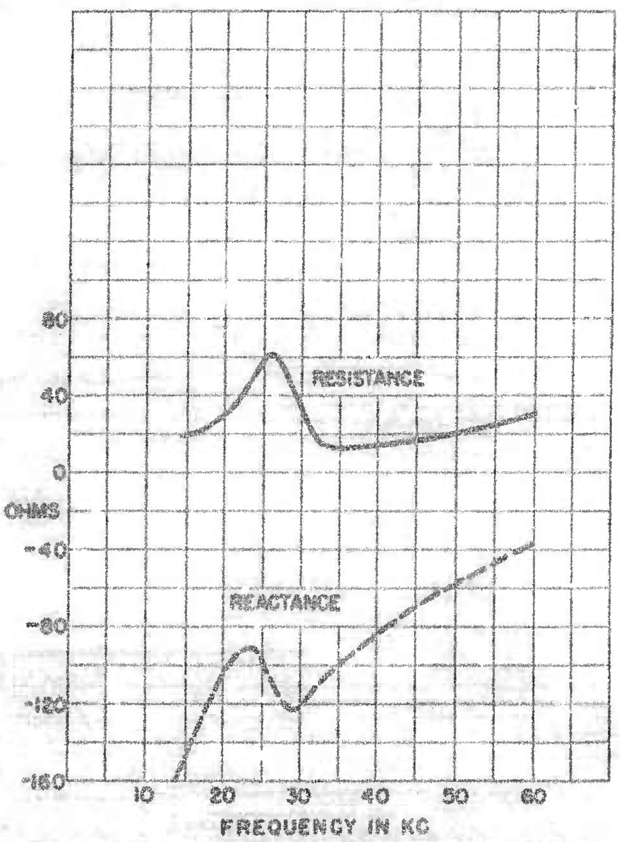


FIGURE 126. Impedance, CBM 78164A projector. R/S unit.

2.7.29 QCU Sonar-Ranging Projector (CRV 78225)

Type: Magnetostriction.

Designer and Manufacturer: RCA Victor Division of the Radio Corporation of America, Type No. MI 16740.

Reference: NDRC Report No. 6.1-sr1130-1379, April 28, 1944.[98]

Application: This projector is a part of the QCU echo-ranging equipment for medium-sized A/S ships.

Description: The CRV 78225 projector is a magnetostriction unit with permanent-magnet polarization. It is approximately 14 in. in diameter. The active elements consist of 182 nickel tubes equally spaced in an equilateral triangle arrangement. The tubes have a length equivalent to one-quarter wavelength at the operating frequency, which is about 25 kc. The nickel tubes have one end imbedded in a circular steel plate ⅝ in. thick which serves as the diaphragm. The diaphragm is bolted to the metal housing over a Corprene gasket. The metal housing is lined outside with a cork, and a coating of neoprene extends over the housing and diaphragm.

Electrical connection to the projector is provided by a series-parallel arrangement of 182 identical coils, with one coil over each nickel tube. The projector is a three-wire unit with the windings series-split for BDI operation.

Impedance at resonance (25.4 kc): $33.8 + j117$ ohms.

Efficiency at resonance: -3.8 db vs ideal.

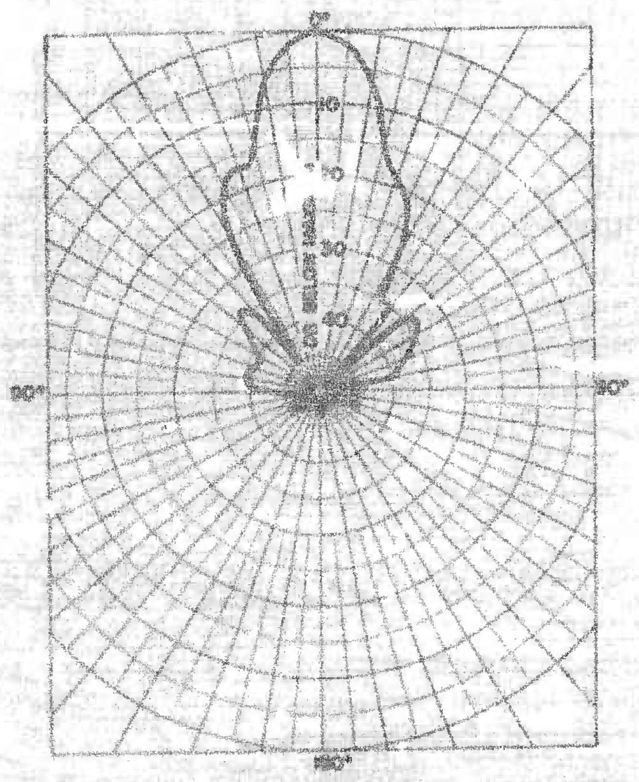


Figure 127. Directivity pattern, CRV 78225 projector at 25.5 kc. Connected series aiding. Directivity index = −22.4 db.

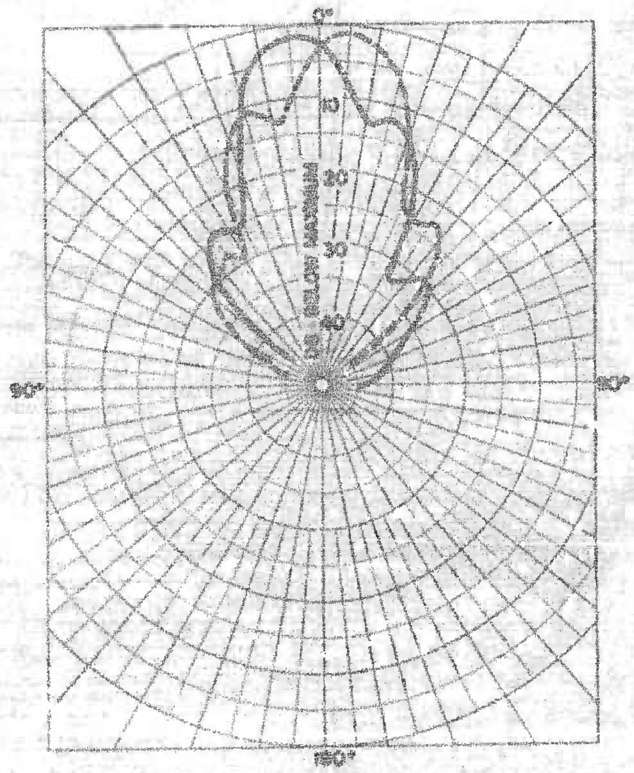


Figure 128. BDI patterns, CRV 78225 projector at 25.5 kc. Electrical phase shift = 70°.

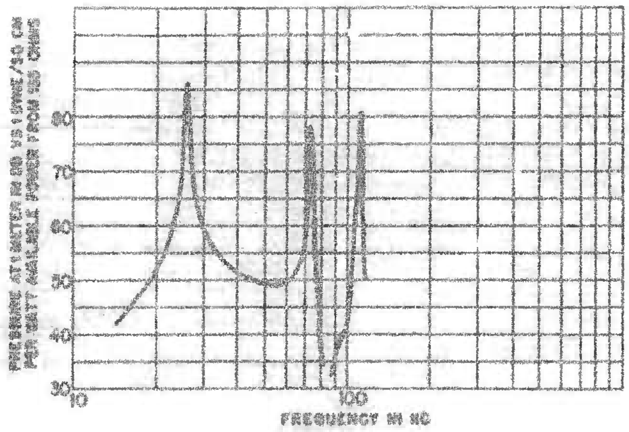


FIGURE 129. Transmitting response, CRV 78225 projector. Connected series aiding. Water temperature = 73 F. Q = 70.

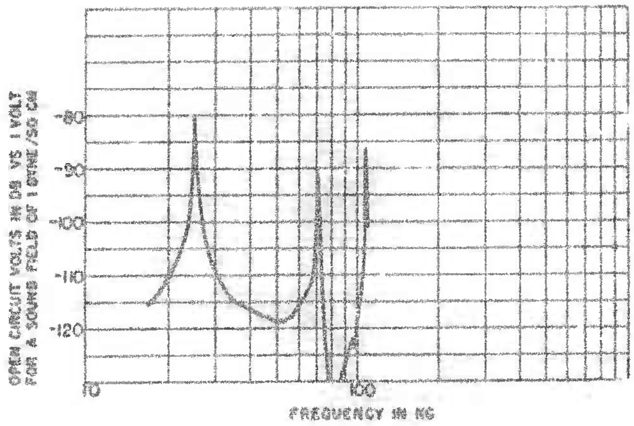


FIGURE 130. Receiving response, CRV 78225 projector. Connected series aiding. Water temperature = 73 F. Q = 70. Calculated threshold at 25.5 kc = −99 db vs 1 dyne/sq cm.

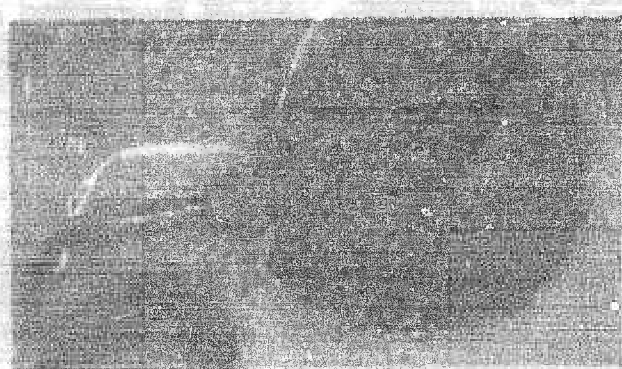


FIGURE 131A. CRV 78225 projector.

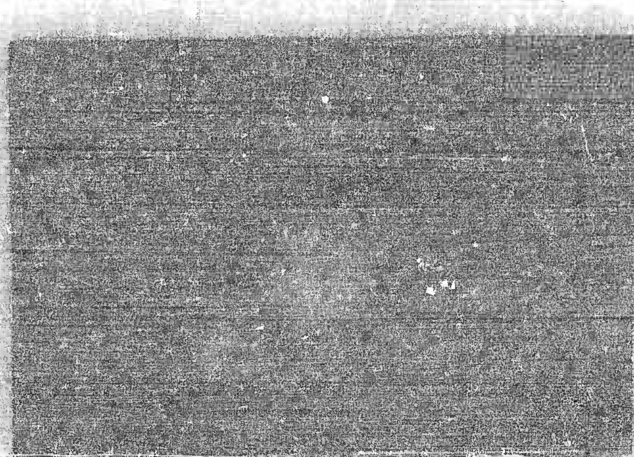


FIGURE 131B. CRV 78225 projector, component parts.

3.7.30 QGA Sonar-Ranging Projector (CBM 78220)

Type: Magnetostriction.

Manufacturer: Submarine Signal Company, Type No. 941.

Reference: NDRC Report No. 6.1-sr1130-1626, June 7, 1944.[67]

Application: The CBM 78220 projector is a major unit in the QGA equipment for echo ranging on large destroyers. This projector is the lower one of two tandem units vertically mounted in a fixed 100-in. dome. The upper unit, CBM 78221 (942), is tiltable to permit ranging in a vertical direction.

Description: This unit is a magnetostrictive type with permanent-magnet polarization. The active elements are nickel tubes with one end imbedded in a heavy steel plate diaphragm. The nickel tube and diaphragm are tuned to resonate at approximately 15 kc. The coil structure consists of a series-parallel arrangement of identical coils surrounding each tube. The projector is parallel-split for BDI operation.

Efficiency at resonance: —7.5 db vs ideal.

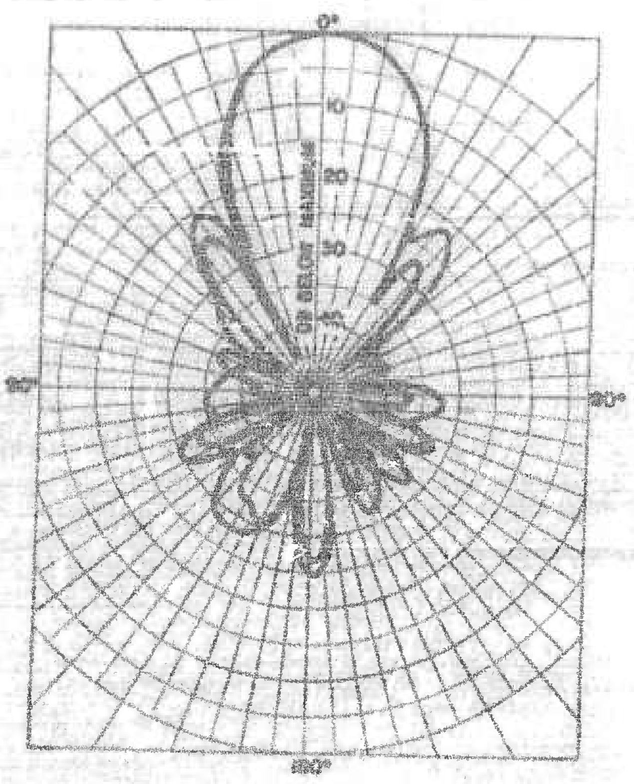


FIGURE 132. Directivity patterns, CBM 78220 projector. Solid line: 1 w available power at 14.8 kc. Directivity index = —18.7 db. Broken line: 400 w input power at 14.74 kc. Directivity index = —18.8 db.

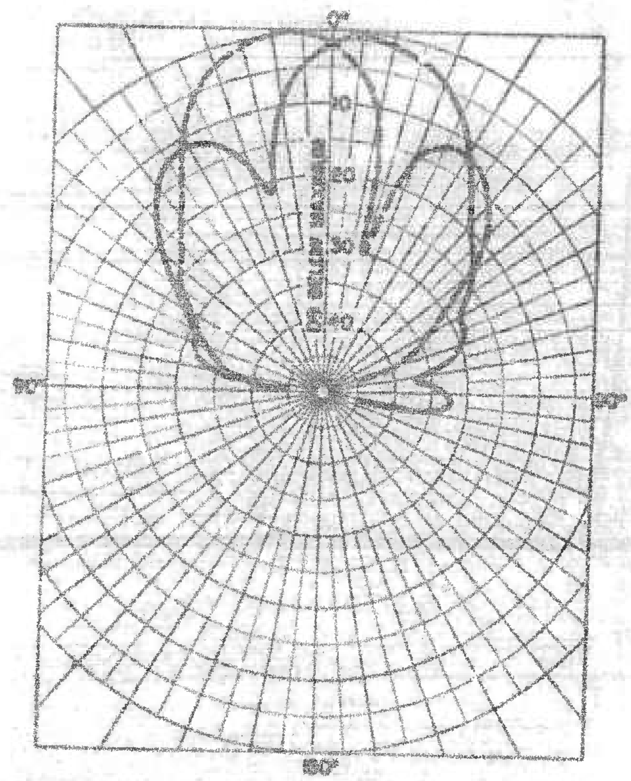


FIGURE 133. BDI patterns, CBM 78220 projector at 14.8 kc. Electrical phase shift = 60°.

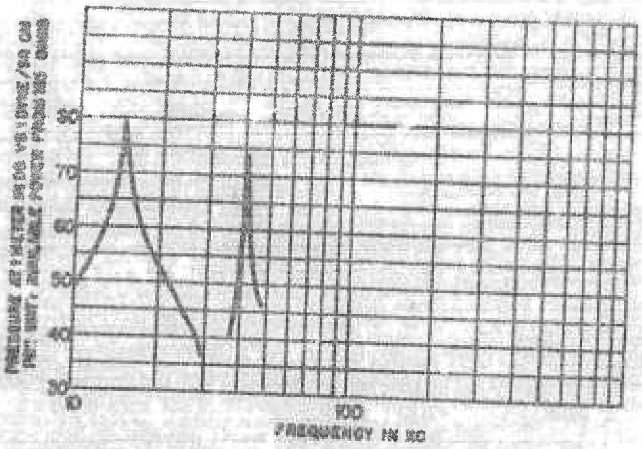


FIGURE 134. Transmitting response, CBM 78220 projector. Water temperature = 52 F. Q = 36.

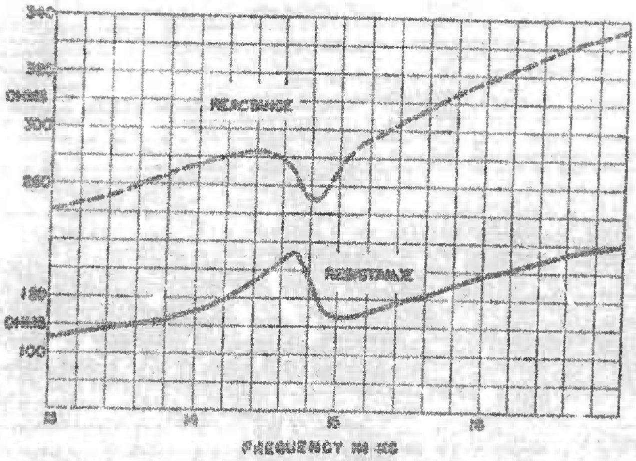


FIGURE 136. Impedance, CBM 78220 projector.

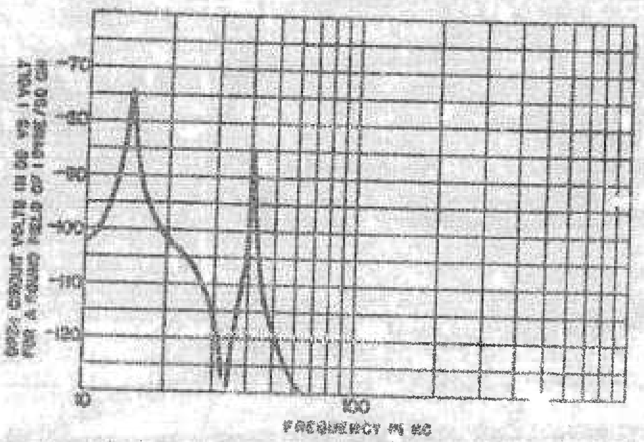


FIGURE 135. Receiving response, CBM 78220 projector. Water temperature = 52 F. Q = 40. Calculated threshold at 14.8 kc = −99 db vs 1 dyne/sq cm.

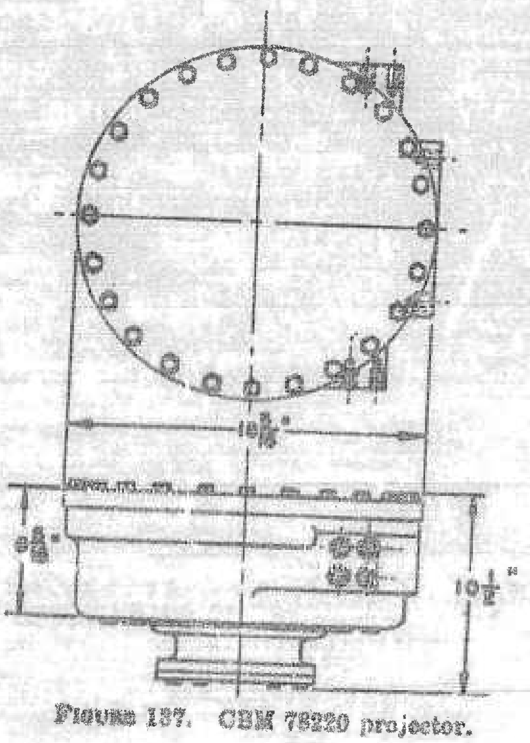


FIGURE 137. CBM 78220 projector.

2.7.31 QGA Sonar-Ranging Projector (CBM 78221)

Type: Magnetostriction.

Manufacturer: Submarine Signal Company, Type No. 942.

Reference: NDRC Report No. 6.1-sr1130-1626, June 7, 1944.[67]

Application: The CBM 78221 projector is a major unit in the QGA equipment for echo ranging on large destroyers. This projector is the upper one of two tandem units vertically mounted in a fixed 100-in. dome. This unit is tiltable to permit ranging in a vertical direction. The lower unit, CBM 78220 (941), is a low-frequency (15 kc) unit for long distance ranging.

Description: This unit is a magnetostrictive type with permanent-magnet polarization. The active elements are nickel tubes with one end imbedded in a steel plate diaphragm. The nickel tubes and diaphragm are mechanically tuned to resonate at approximately 30 kc. The coil structure consists of a series-parallel arrangement of identical coils, one of which surrounds each tube. The projector is parallel-split for BDI operation.

Efficiency at resonance: —7.5 db vs ideal.

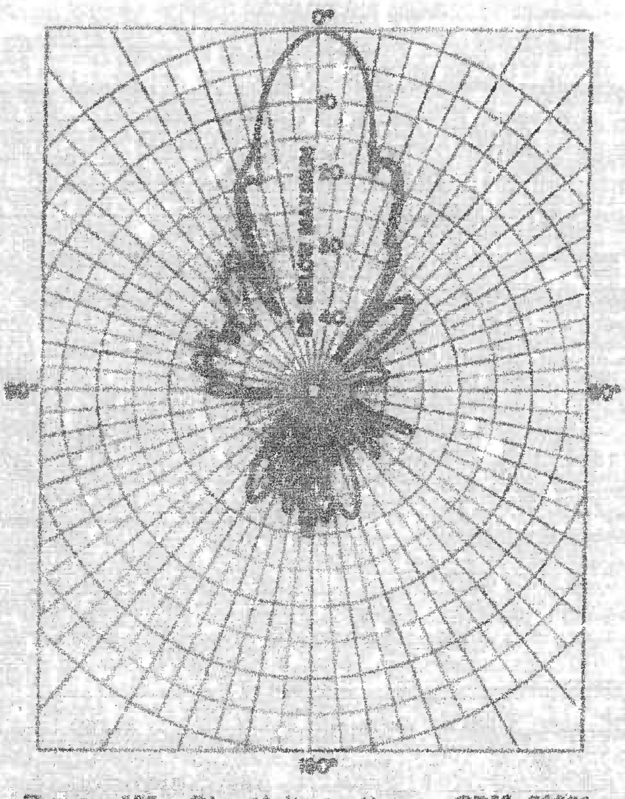


FIGURE 138. Directivity patterns, CBM 78221 projector. Solid line: 1 w available power at 30.46 kc. Directivity index = —22.2 db. Broken line: 400 w input power at 30.49 kc. Directivity index = —22.4 db.

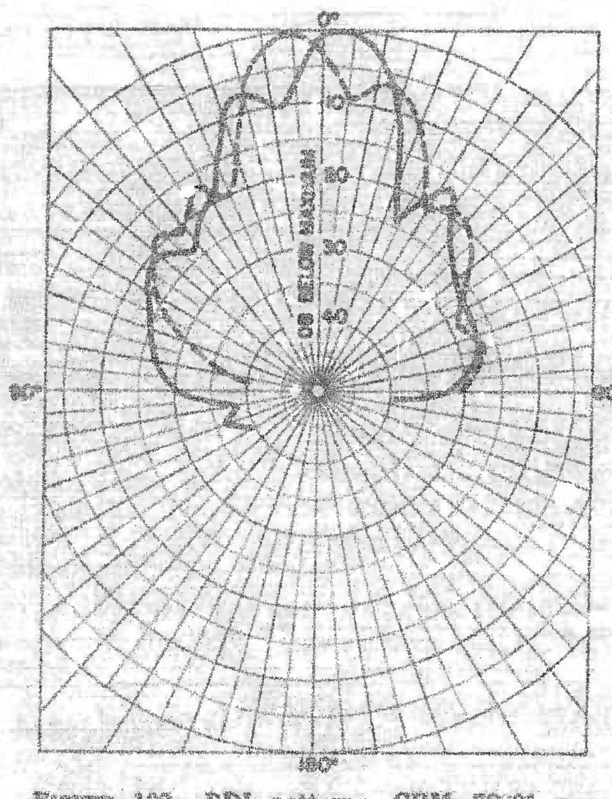


FIGURE 139. BDI patterns, CBM 78221 projector at 30.47 kc. Electrical phase shift = 60°.

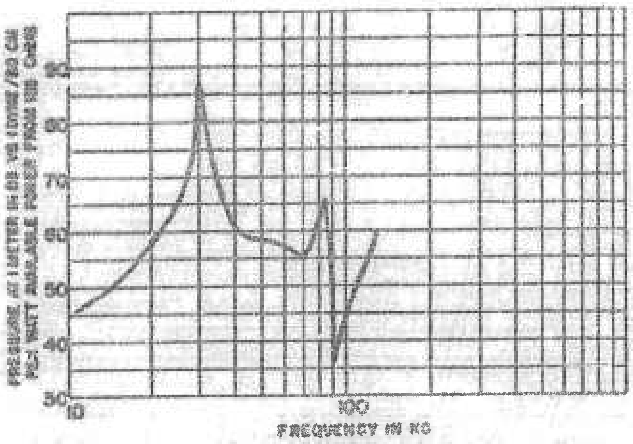


FIGURE 140. Transmitting response, CBM 78221 projector. Water temperature = 80 F. Q = 25.8.

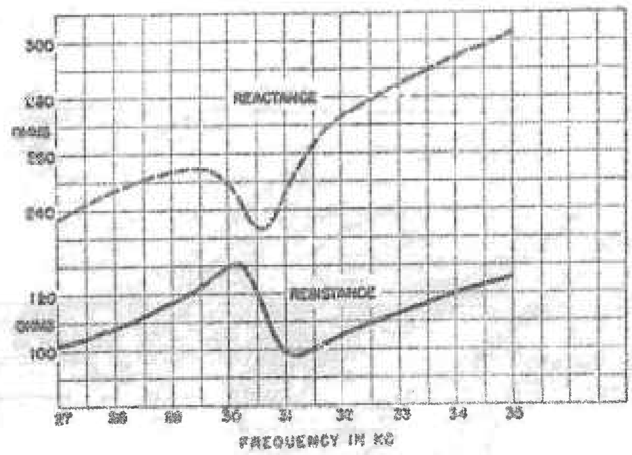


FIGURE 142. Impedance, CBM 78221 projector.

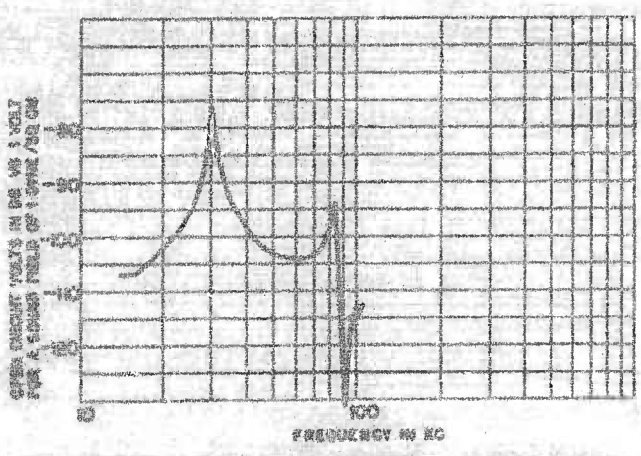


FIGURE 141. Receiving response, CBM 78221 projector. Water temperature = 80 F. Q = 25.2. Calculated threshold at 30.5 kc = −98 db vs 1 dyne/sq cm.

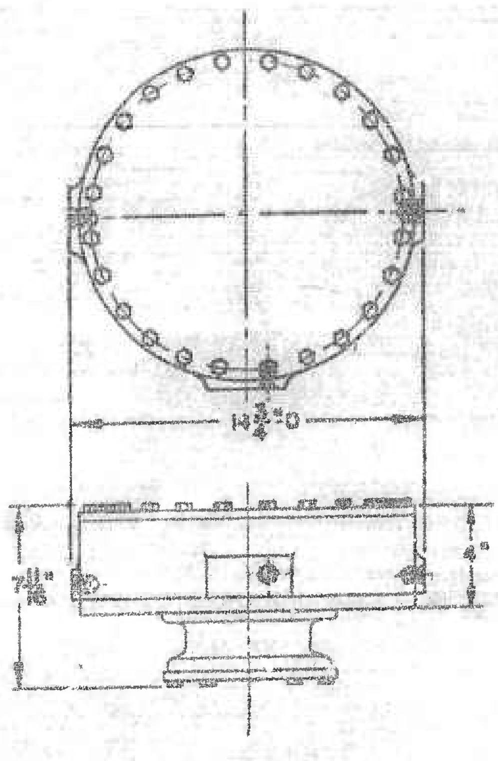


FIGURE 143. CBM 78221 projector.

2.7.32 QGB Sonar-Ranging Projector (CRV 78210)

Type: Magnetostriction.

Manufacturer: RCA Victor Division of the Radio Corporation of America, Type No. MI 16727-3.

Reference: NDRC Report No. 6.1-sr1130-1985, January 16, 1945.[72]

Application: This projector is normally used in the QGB sonar ranging equipment for large A/S ships mounted in a retractable-type dome. This unit is arranged for BDI operation.

Description: The CRV 78210 projector is a magnetostriction unit with permanent magnet polarization. Series-split connections to the two halves of the projector are provided for BDI operation. The projector is designed to operate from a transmitting source of 100 ohms at 400 w electric power input.

Four types of the QGB projector, differing only in frequency of resonance, are supplied. These types are designated as:

Frequency	*U. S. Navy No.*	*Mfg. No.*	*Equipment*
20 kc	CRV 78208	MI 16727-4	QGB
22 kc	CRV 78209	MI 16727-1	QGB
24 kc	CRV 78210	MI 16727-3	QGB
26 kc	CRV 78211	MI 16727-2	QGB

Efficiency: CRV 78210 projector at resonance: —6.6 db vs ideal.

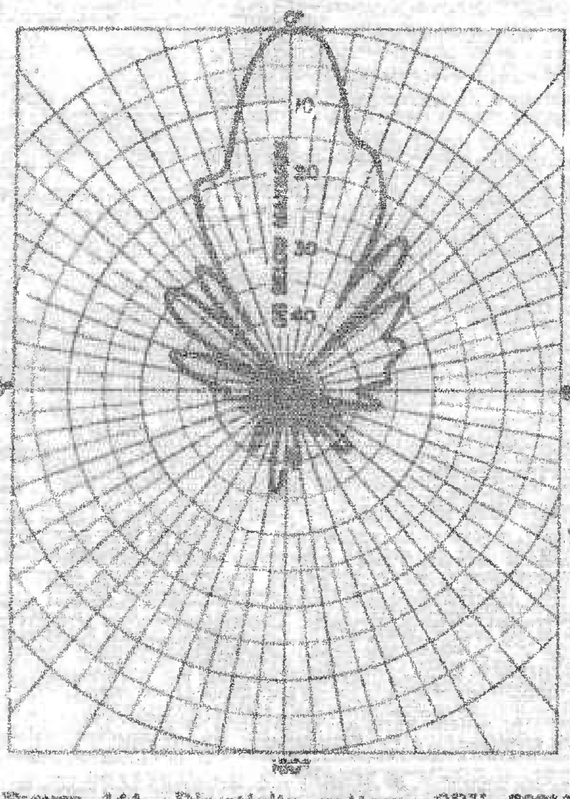


FIGURE 144. Directivity pattern, CRV 78210 projector at 24.5 kc. Directivity index = —22.6 db.

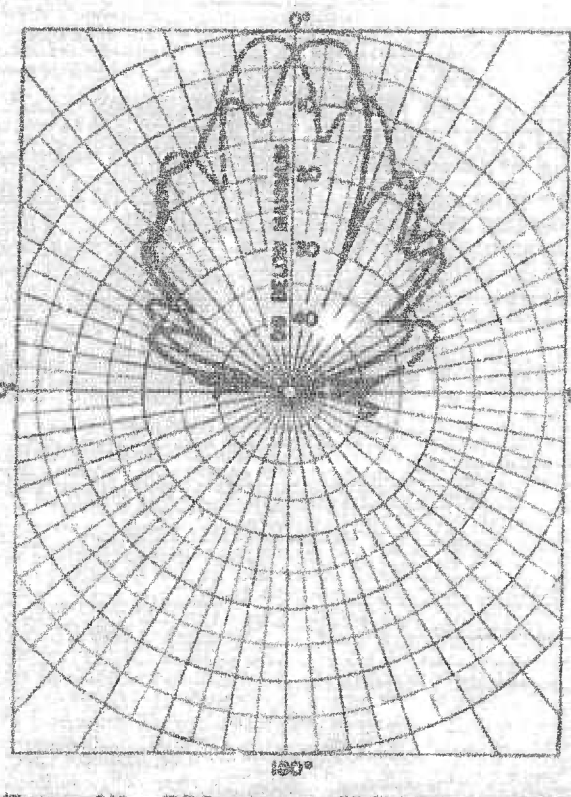


FIGURE 145. BDI patterns, CRV 78210 projector at 24.5 kc. Electrical phase shift = 81.8°.

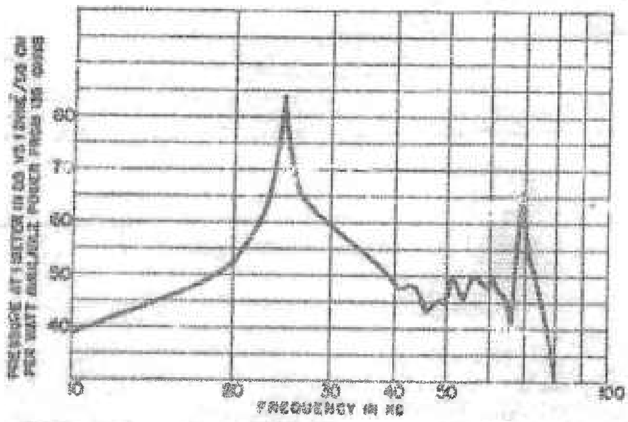


FIGURE 146. Transmitting response, CRV 78210 projector. Water temperature = 66 F. Q = 70.

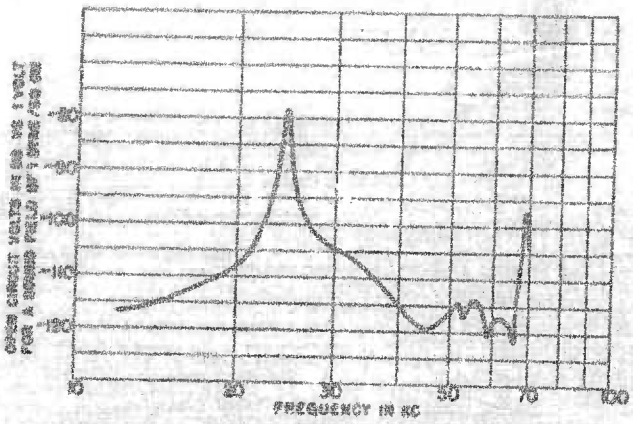


FIGURE 147. Receiving response, CRV 78210 projector. Water temperature = 66 F. Q. = 77. Calculated threshold at 24.5 kc = −101 db vs 1 dyne/sq cm.

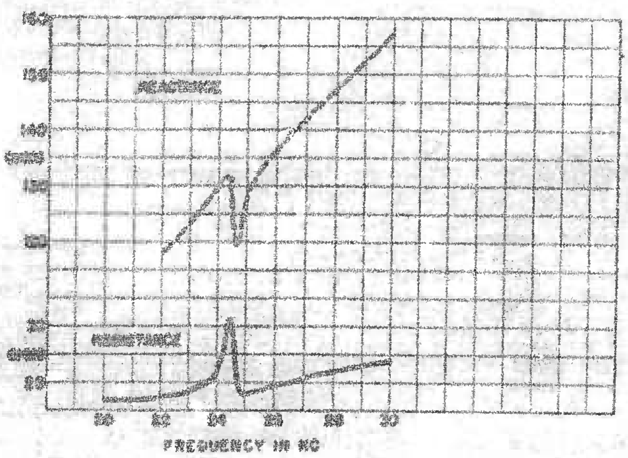


FIGURE 148. Impedance, CRV 78210 projector.

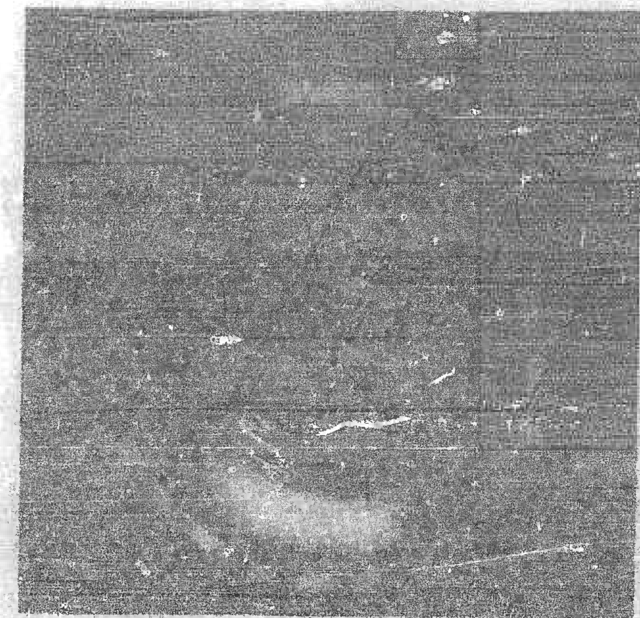


FIGURE 149A. CRV 78210 projector.

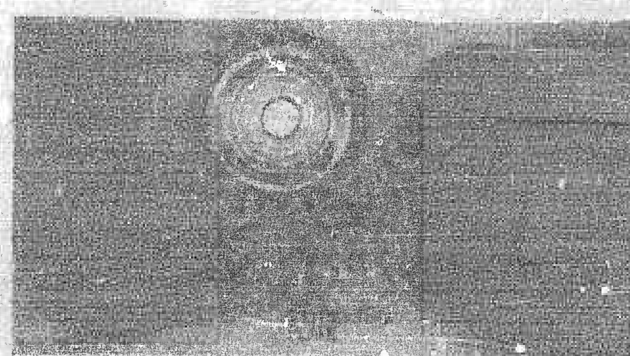


FIGURE 149B. CRV 78210 projector, component parts.

2.7.28 QJB Sonar-Ranging Projector (CW 78207)

Type: ADP Crystal.

Designer: Bell Telephone Laboratories.

Manufacturer: Western Electric Company, Type No. D-166471.

Reference: NDRC Report No. 6.1-sr1130-1986, January 16, 1945.[73]

Application: This CW 78207 unit is used as the projector in QBF and in QJA echo-ranging equipments for ranging on objects at distances up to 10,000 yd. The CW 78207 and the CW 78178 projectors are interchangeable.

Description: The CW 78207 projector is similar to the CW 78178, except that the active elements in the CW 78207 unit consist of ADP crystals instead of Y-cut Rochelle salt crystals. In external appearance it is identical with the QBF (CW 78178) projector.

Efficiency at 24 kc: —4.0 db vs ideal.

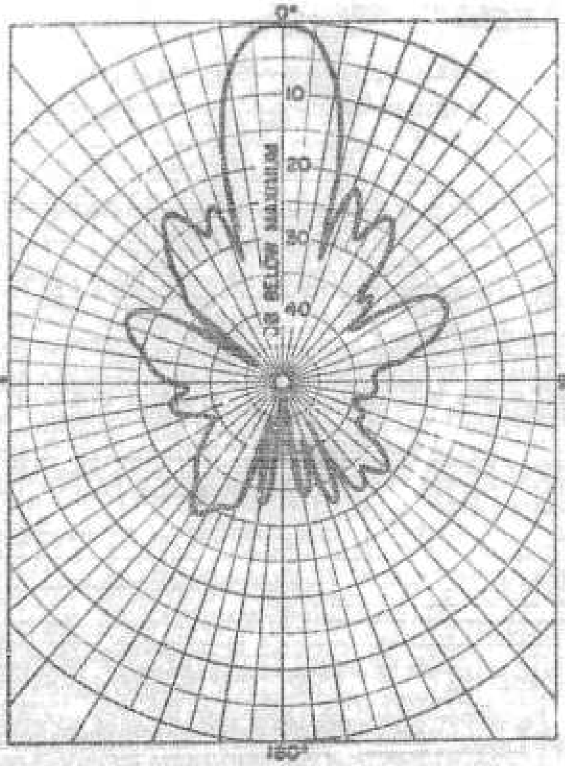


FIGURE 150. Directivity pattern, CW 78207 projector at 24 kc. Connected parallel aiding. Directivity index = —22.8 db.

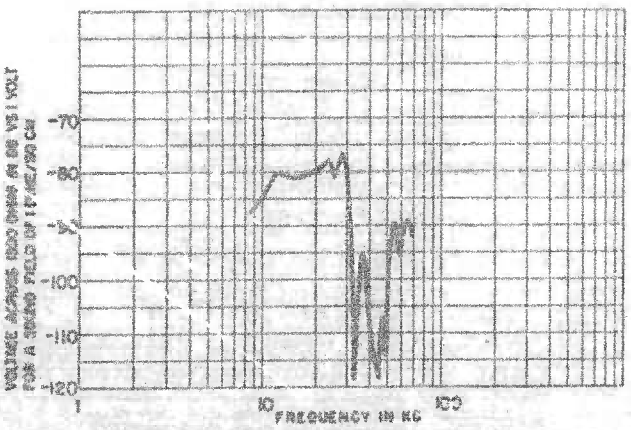


FIGURE 152. Receiving response, CW 78207 projector. Connected parallel aiding. Water temperature = 60 F. Calculated threshold at 24 kc = —101.8 db vs 1 dyne/sq cm.

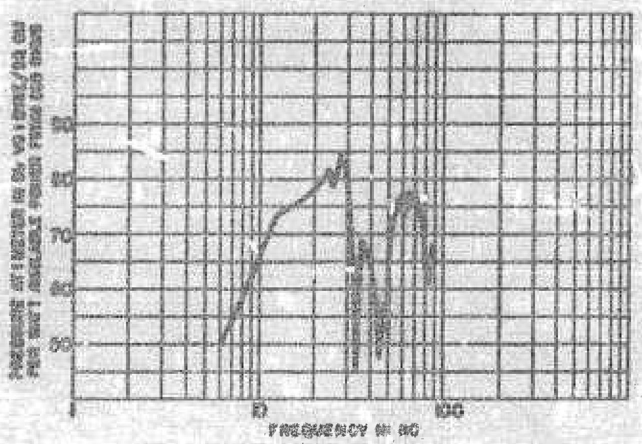


FIGURE 151. Transmitting response, CW 78207 projector. Connected parallel aiding. Water temperature = 60 F.

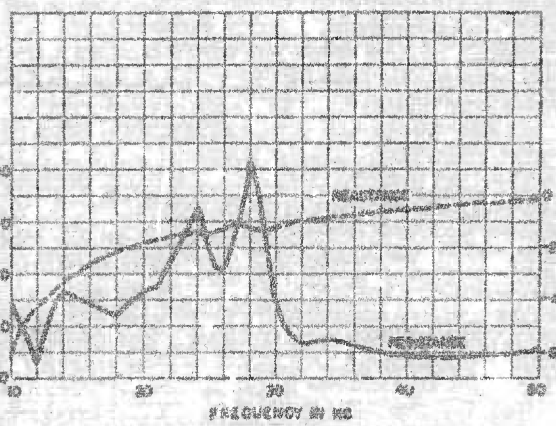


FIGURE 153. Impedance, CW 78207 projector. Connected parallel aiding.

2.2.34 WCA-1 Sonar-Ranging Projector (CBM 78153)

Type: Combination Magnetostriction and Rochelle Salt Crystal.
Manufacturer: Submarine Signal Company, Type No. 733H.
Reference: USRL Orlando Project No. 137, January 1945.

Application: The CBM 78153 projector consists of a magnetostriction (QC) unit and a Rochelle salt (JK) unit in a spherical housing. It is one of three projectors used in the WCA and WCA-1 equipments for submarines. These two equipments differ only in the voltage of the d-c power supply. The CBM 78153 projector is mounted on the port side of the ship. The magnetostriction or QC unit of this projector is used for echo ranging at 24 kc, and the Rochelle salt or JK unit is used for supersonic listening. A second QB-type Rochelle salt crystal projector, CBM 78154 (733J), is mounted on the starboard side of the ship and may be used for echo ranging at any frequency in the range 14 to 32 kc. A third projector, CBM 78155 (763J), is mounted on the bottom of the hull and is used for depth sounding at 24 kc. The ranging equipment can be used for telegraphic communication between vessels similiarly equipped.

Description: The CBM 78153 combination projector consists of a magnetostriction unit and a Rochelle salt unit mounted back to back on a common frame. With hemispherical covers the projector is spherical in shape and 19 in. in diameter.

The M/S unit consists of a group of nickel tubes firmly imbedded in a steel diaphragm. The nickel tubes and diaphragm are designed to resonate at about 24 kc. Each tube is surrounded by a coil through which flows the d-c polarizing current and the pulses of 24 kc supplied by the driver. A total polarizing current of approximately 7.5 amp is required. The unit is not arranged for BDI. A hemispherical stainless steel shell is fastened over the diaphragm and the cavity is filled with a 50 per cent mixture of ethylene glycol and water.

The R/S unit has a number of X-cut Rochelle salt crystals mounted on a steel backing plate. The opposite faces of the crystals are in one plane and form the sound receiving surface. A hemispherical rubber shell encloses the crystals, and the cavity between the crystals and the shell is filled with air-free castor oil.

Impedance: M/S unit at resonance: $93 + j148$ ohms.
R/S unit at 24 kc: $45 - j118$ ohms.

Efficiency: M/S unit at resonance: —13.0 db vs ideal.
R/S unit at 24 kc: —2.0 db vs ideal.

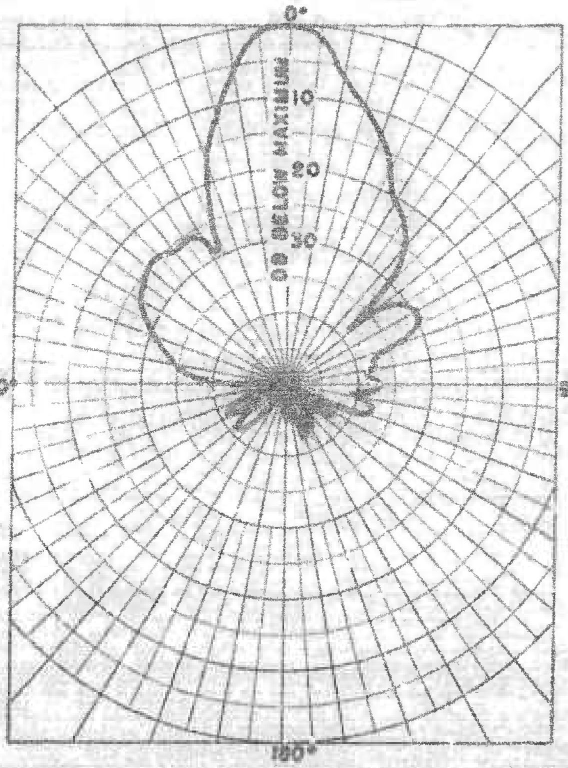


FIGURE 154. Directivity pattern, CBM 78153 projector at 24.22 kc. M/S unit. Directivity index = —20.7 db.

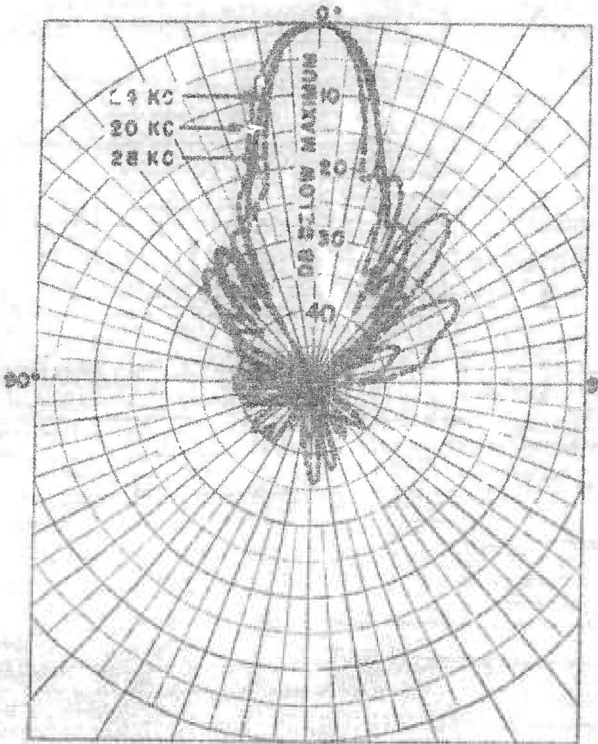


FIGURE 155. Directivity patterns, CBM 78153 projector. R/S unit. Directivity index: at 20 kc = —22.2 db, at 24 kc = —23.2 db, at 28 kc = —24.8 db.

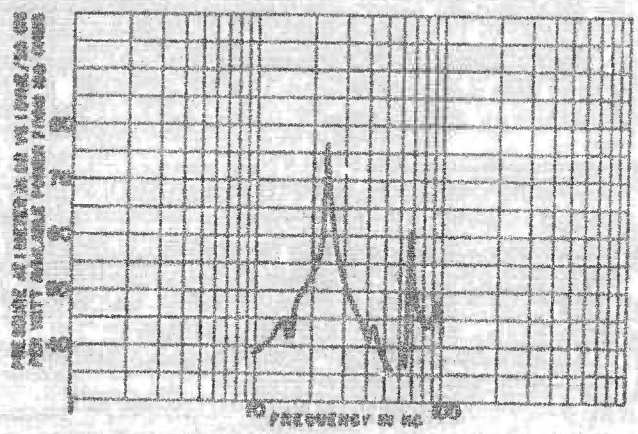


FIGURE 156. Transmitting response, CBM 78153 projector. M/S unit. Water temperature = 63 F. Q = 54.

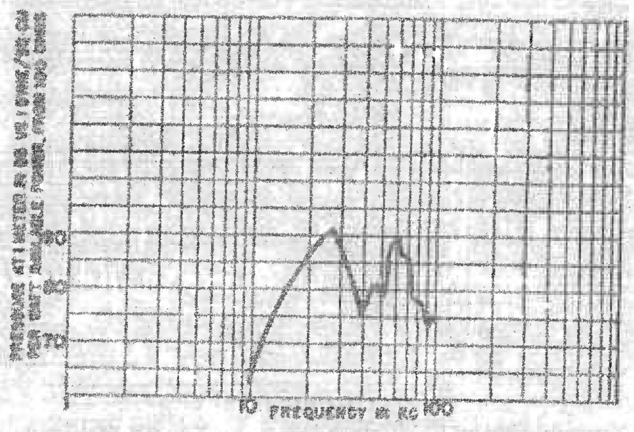


FIGURE 157. Transmitting response, CBM 78153 projector. R/S unit. Water temperature = 61 F.

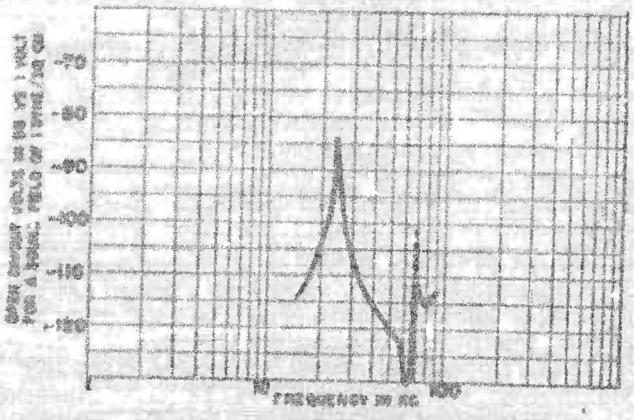


FIGURE 158. Receiving response, CBM 78153 projector. M/S unit. Water temperature = 63 F. Q = 44. Calculated threshold at 24.22 kc = 91.5 db vs 1 dyne/sq cm.

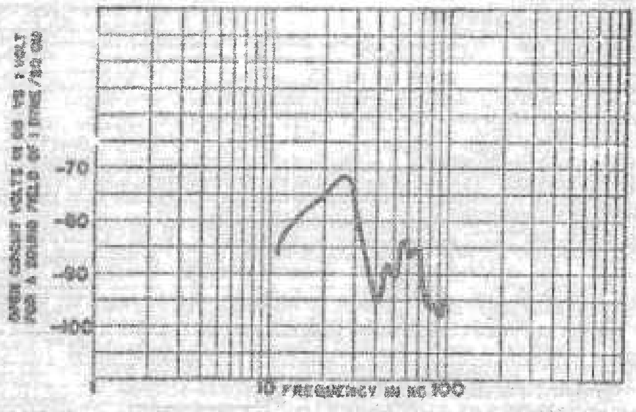


FIGURE 159. Receiving response, CBM 78153 projector. R/S unit. Water temperature = 61 F. Calculated threshold at 24 kc = —106 db vs 1 dyne/sq cm.

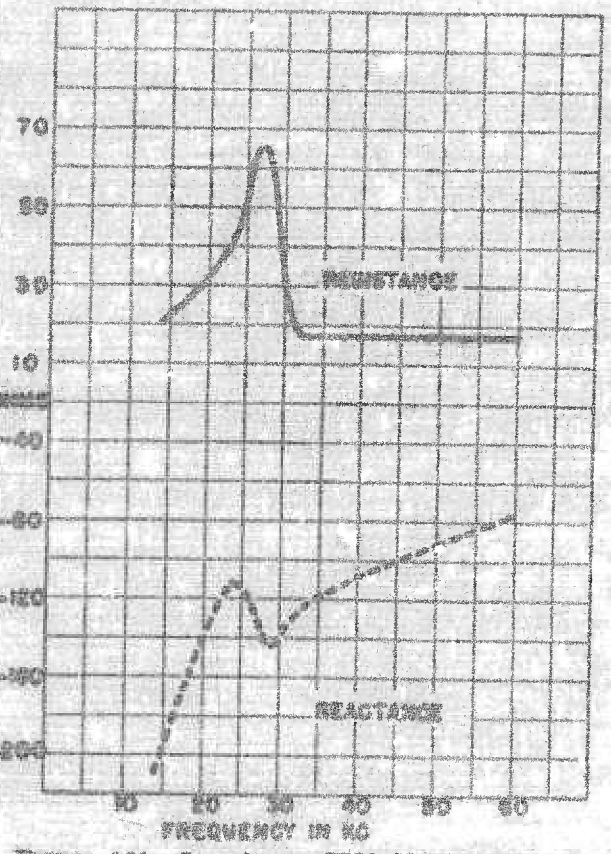


FIGURE 160. Impedance, CBM 78153 projector. R/S unit.

8.7.35 WCA-2 WEB Sonar-Ranging Projector (CBM 78212)

Type: Combination Magnetostriction and Rochelle Salt Crystal.
Designer and Manufacturer: Submarine Signal Company, Type No. 948.
Reference: USRL Orlando Project No. 137, January 1945.

Application: The CBM 78212 projector, consisting of a magnetostriction unit and a Rochelle salt unit in one housing, is used for echo ranging, telegraphic communication, and for listening in the WCA-2 and WEB equipments for submarines. This projector is used in combination with the CBM 78214 sounding projector in the WEB equipment and in combination with the CBM 78213 R/S echo-ranging projector and the CBM 78214 sounding projector in the WCA-2 equipment.

Description: The CBM 78212 projector is a combination magnetostriction unit and a Rochelle salt unit in a spherical housing. The diameter is approximately 19 in.

The magnetostriction echo-ranging unit consists of a group of nickel tubes which are attached at one end to the circular steel plate serving as the diaphragm. The nickel tubes and diaphragm are tuned to resonate at approximately 24 kc. The coil structure consists of a series-parallel arrangement of identical coils, with one coil surrounding each tube. The coils carry the 24-kc driving current. The unit contains a permanent magnet and is parallel-split for BDI operation. The diaphragm is covered by a hemispherical shell of stainless steel. The space between the diaphragm and cover is free-flooded.

The Rochelle salt listening unit consists of a group of X-cut Rochelle salt crystal blocks mounted on a steel backing plate. The crystals are enclosed by a hemispherical rubber cover, and the space between the crystals and cover is filled with air-free castor oil.

Efficiency: M/S unit at resonance: —10.0 db vs ideal.
R/S unit at 24 kc: —2.1 db vs ideal.

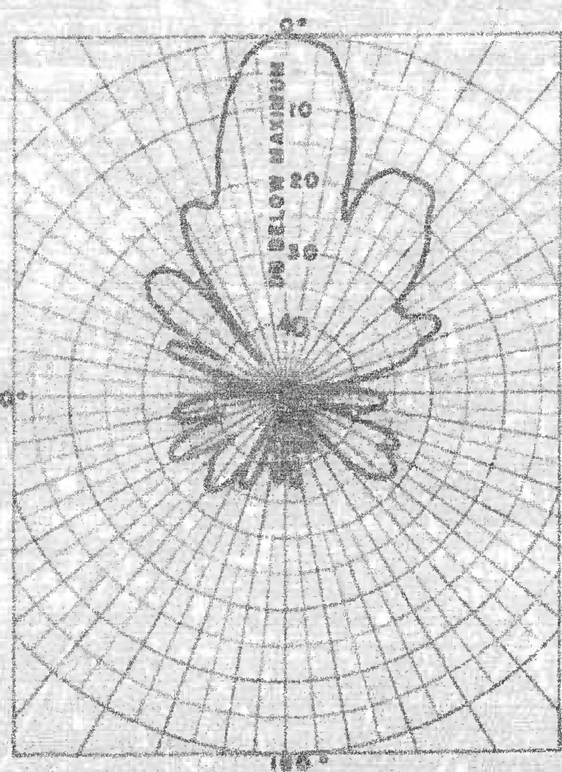


FIGURE 161. Directivity pattern, CBM 78212 projector at 23.88 kc. M/S unit. Connected parallel siding. Directivity index = −21.2 db.

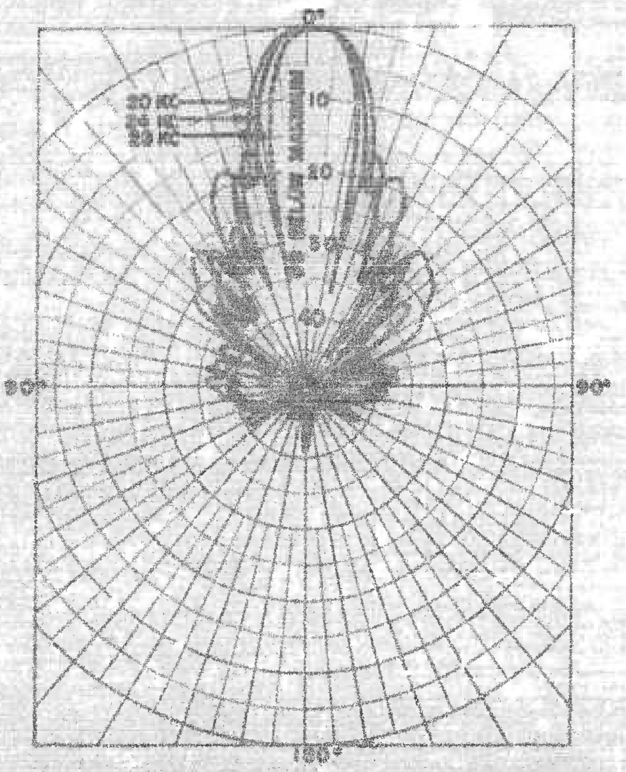


FIGURE 162. Directivity patterns, CBM 78212 projector. R/S unit. Directivity index: at 20 kc = −22.2 db, at 24 kc = −23.5 db, at 28 kc = −24.8 db.

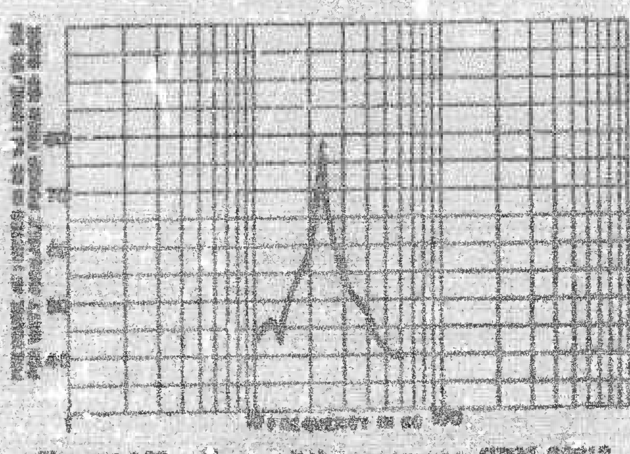


FIGURE 163. Transmitting response, CBM 78212 projector. M/S unit. Connected parallel siding. Water temperature = 61 F. Q = 35.

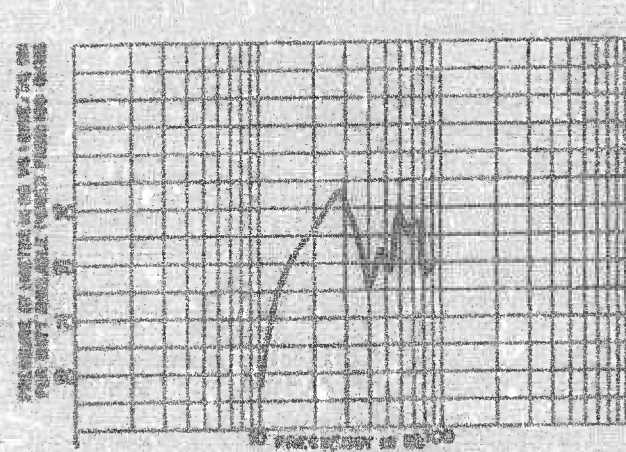


FIGURE 164. Transmitting response, CBM 78212 projector. R/S unit. Water temperature = 6[illegible] F.

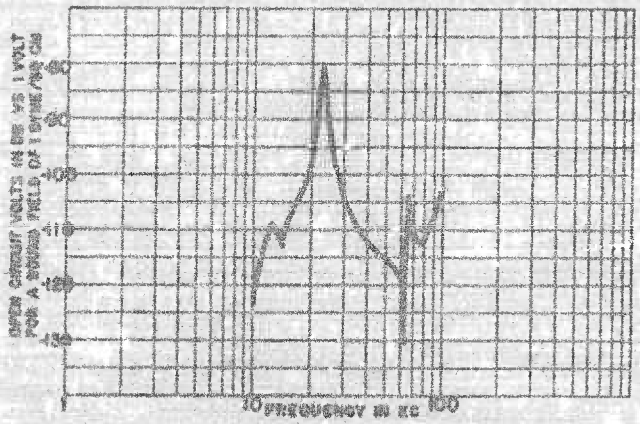


FIGURE 165. Receiving response, CBM 78212 projector. M/S unit. Connected parallel siding. Water temperature = 61 F. Q = 31. Calculated threshold at 23.55 kc = −95.5 db vs 1 dyne/sq cm.

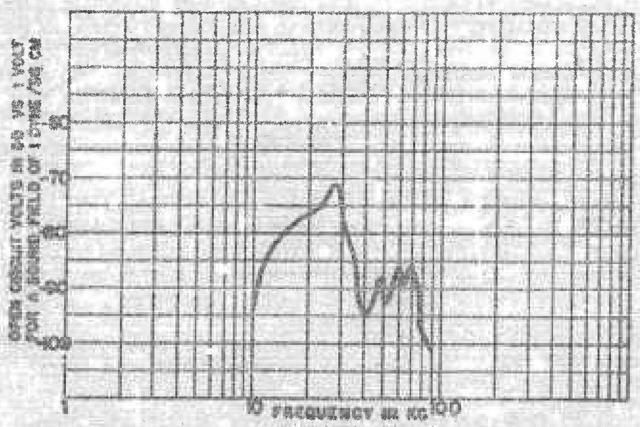


FIGURE 166. Receiving response, CBM 78212 projector. R/S unit. Water temperature = 62 F. Calculated threshold at 24 kc = −105 db vs 1 dyne/sq cm.

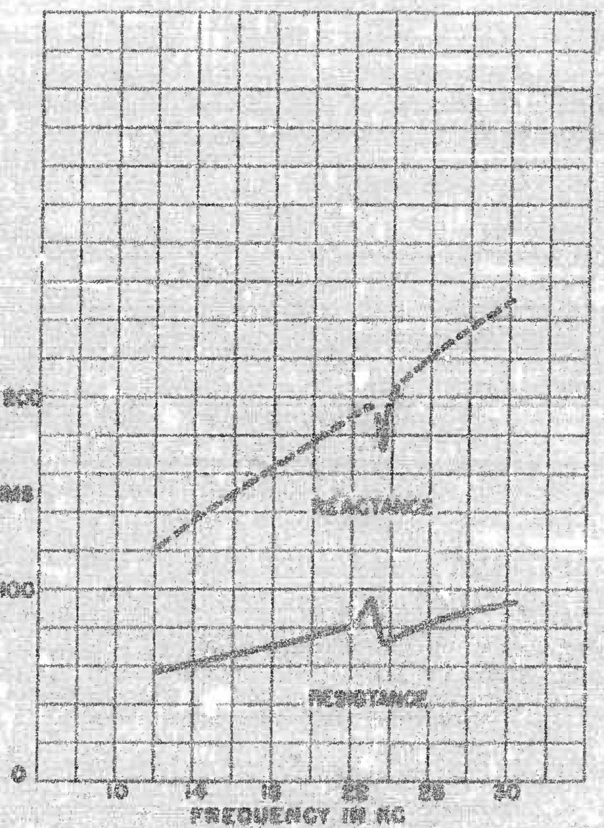


FIGURE 167. Impedance, CBM 78212 projector. M/S unit.

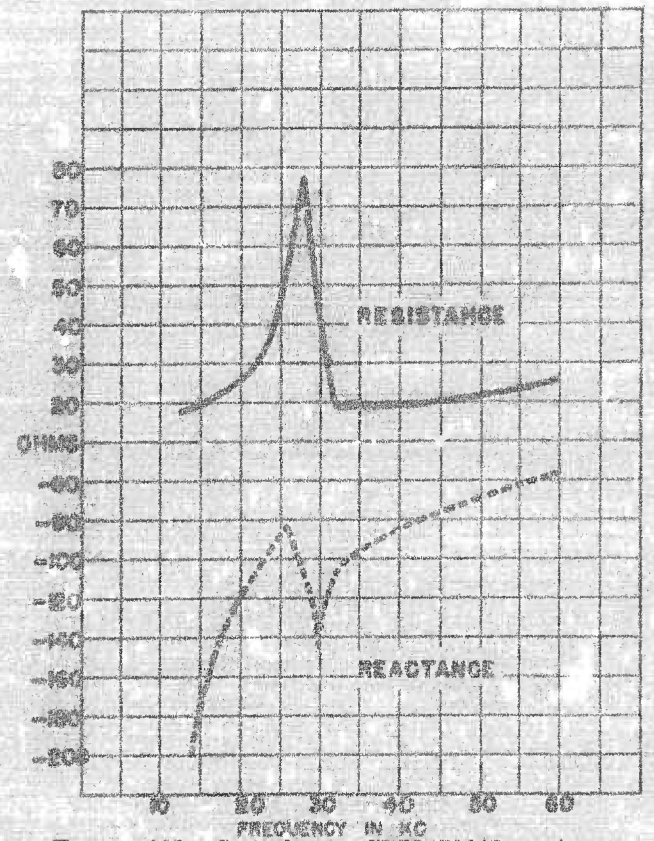


FIGURE 168. Impedance, CBM 78212 projector. R/S unit.

2.7.36 WCA-2 Sonar-Ranging Projector (CBM 78213)

Type: 45° X-Cut Rochelle Salt Crystal.

Designer and Manufacturer: Submarine Signal Company, Type No. 783R.

Reference: NDRC Report No. 6.1-sr1130-1820, August 11, 1944.[60]

Application: The CBM 78213 projector is used for ranging and listening in the WCA-2 equipment. Its function is to enable the operator to listen to and determine the bearing of high-frequency sound generated by the propellers or other moving parts of a distant vessel. In the WCA-2 equipment this projector is used in combination with the CBM 78212 projector for echo ranging and telegraphic communication with other vessels similarly equipped, and with the CBM 78214 projector for echo sounding.

Description: This projector has 45° X-cut Rochelle salt crystals connected in parallel as its active elements. The crystal assembly is enclosed in a sphere of about 19 in. diameter, with the front hemisphere made of rubber. The space between the crystals and the front cover is filled with castor oil. The crystal assembly is split vertically for BDI operation.

Efficiency at 24 kc: —2.8 ± 1 db vs ideal.

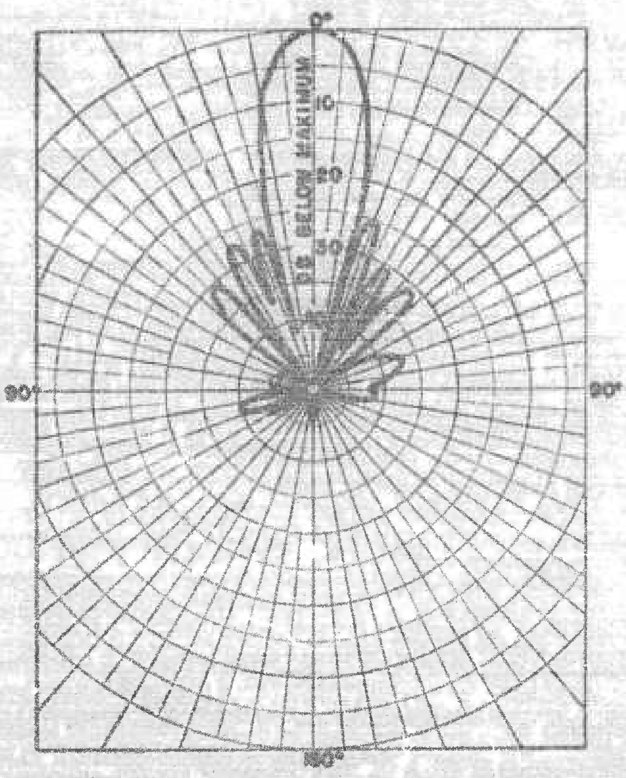


FIGURE 169. Directivity pattern, CBM 78213 projector at 24 kc. Directivity index = —24.2 db.

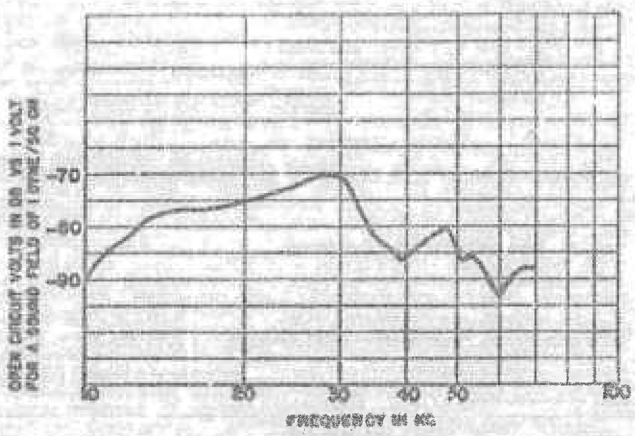


FIGURE 171. Receiving response, CBM 78213 projector. Water temperature = 64 F. Calculated threshold at 24 kc = —106 db vs 1 dyne/sq cm.

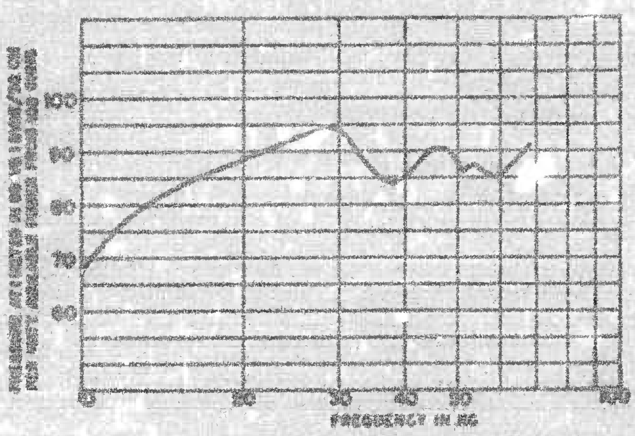


FIGURE 170. Transmitting response, CBM 78213 projector. Water temperature = 64 F.

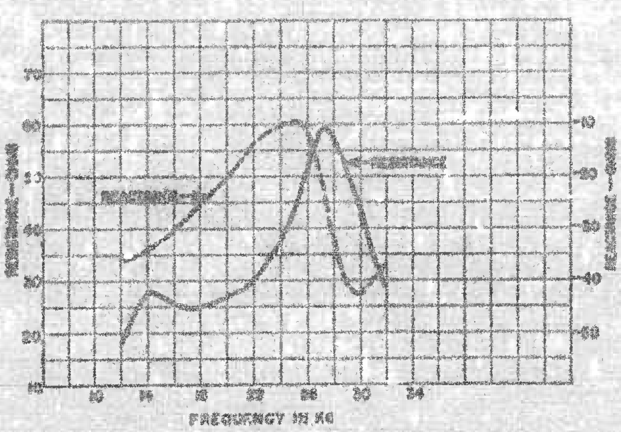


FIGURE 172. Impedance, CBM 78213 projector.

2.7.37 WEA-1 Sonar-Ranging Projector (CRV 78151)

Type: Magnetostriction.

Manufacturer: RCA Victor Division of the Radio Corporation of America, Type No. MI 8992.

Reference: NDRC Report No. 6.1-sr20-607, February 25, 1943.[49]
NDRC Report No. 6.1-sr20-951, August 24, 1943.[88]
NDRC Report No. 6.1-sr20-954, September 2, 1943.[90]
NDRC Report No. 6.1-sr20-959, October 15, 1943.[91]

Application: The CRV 78151 projector is used in the WEA-1 sonar equipment for small A/S ships for echo ranging and listening only. The 45° baffle, originally installed in the WEA-1 dome to permit the same projector to be used for depth sounding, has been removed. Recent units incorporate a Corprene band to reduce rear response, and the windings are split for BDI.

Description: The CRV 78151 projector is a permanent-magnet magnetostrictive type in a banjo-shaped housing approximately 9 in. in diameter. The active element consists of a group of nickel tubes with one end imbedded in the circular steel plate serving as the diaphragm. The coil assembly consists of a series-parallel arrangement of identical coils, one coil surrounding each tube. These coils carry the pulses of 24-kc driving current.

Efficiency at resonance: —6.5 db vs ideal.

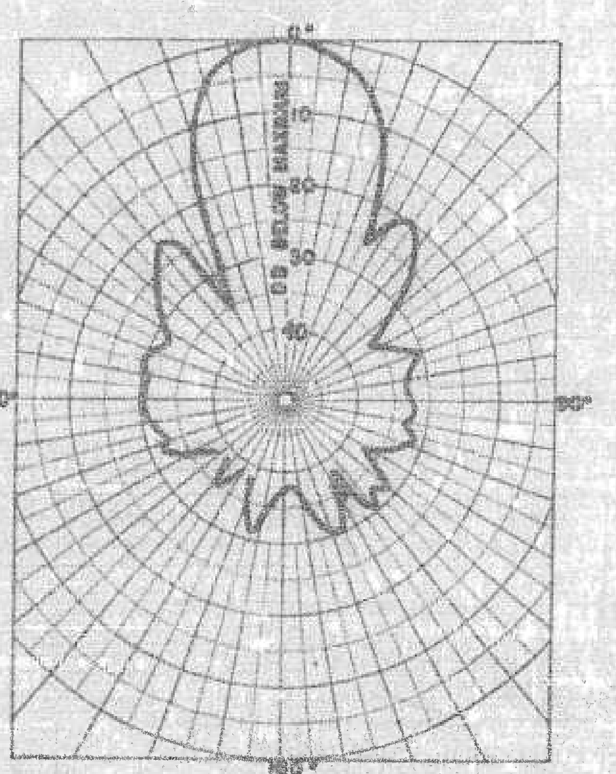


FIGURE 173. Directivity pattern, CRV 78151 projector at 24.6 kc. Directivity index = —19 db.

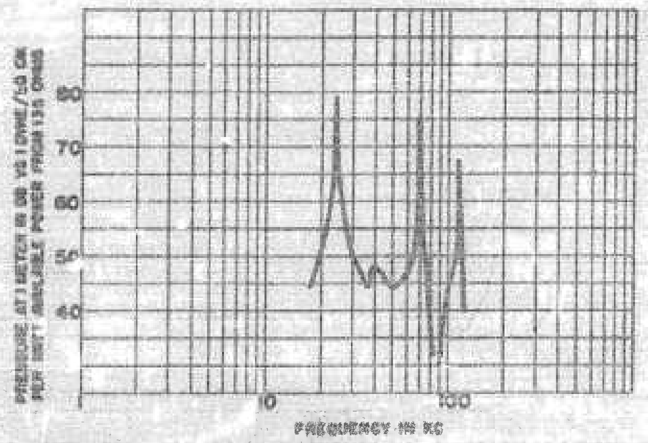


FIGURE 174. Transmitting response, CRV 78151 projector. Water temperature = 69 F. Q = 75.

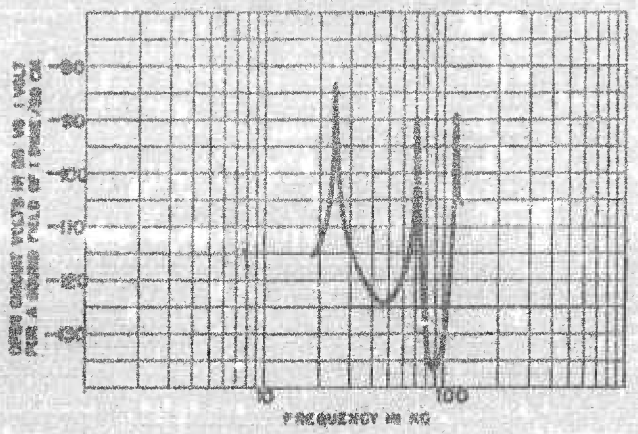


FIGURE 175. Receiving response, CRV 78151 projector. Water temperature = 69 F. Q = 80. Calculated threshold at 24.6 kc = —97 db vs 1 dyne/sq cm.

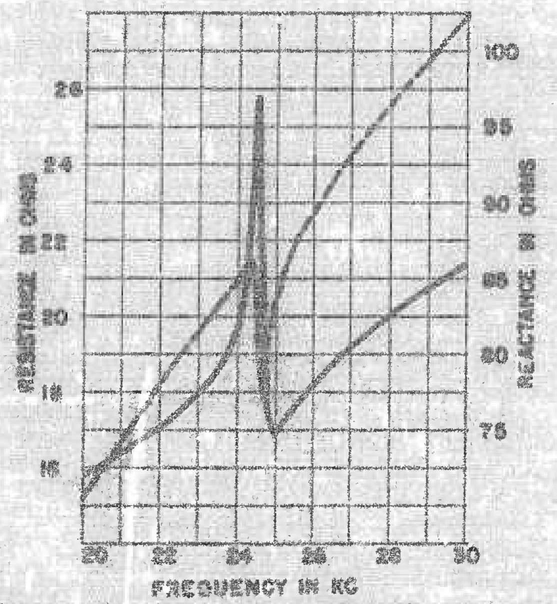


FIGURE 176. Impedance, CRV 78151 projector.

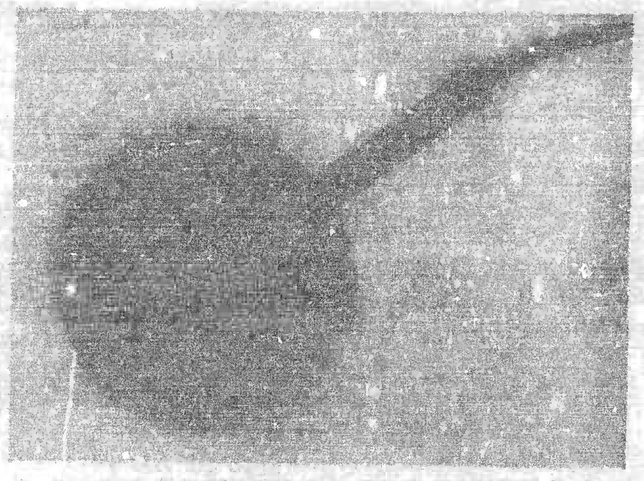


FIGURE 177A. CRV 78151 projector.

FIGURE 177B. CRV 78151 projector, component parts.

2.7.26 WEA-2 Sonar-Ranging Projector (CBM 78156)

Type: Combination Magnetostriction and Rochelle Salt Crystal.

Designer and Manufacturer: Submarine Signal Company, Type No. 885.

Reference: NDRC Report No. C4-sr20-295, November 16, 1942.[46]

Application: The CBM 78156 projector is a major unit in the WEA-2 equipment for ranging, listening, and sounding on small A/S vessels. Sounding is accomplished in this equipment with the projector in combination with a 45° baffle in the tail section of the WEA-2 torpedo-shaped dome to direct the acoustic pulses downward.

Description: The CBM 78156 projector is a combination magnetostriction and Rochelle salt crystal unit in a banjo-shaped housing 14 in. in diameter. The magnetostriction, or QC, face has an effective diameter of about 12½ in. at its normal operating frequency of 24 kc. It requires a polarizing current of 3 amp. The recommended maximum a-c input voltage is 200 v. The d-c resistance of the windings is about 20 ohms.

The crystal, or JK, face of the projector has an effective diameter of about 11 in. The recommended maximum input voltage is 100 v, 100 w, and for intermittent use 145 v, 145 w.

Impedance at 24 kc: M/S unit: $382 + j451$ ohms.
R/S unit: $55.3 - j18.6$ ohms.

Efficiency at 24 kc: M/S unit: —11.5 db vs ideal.
R/S unit: —3 db vs ideal.

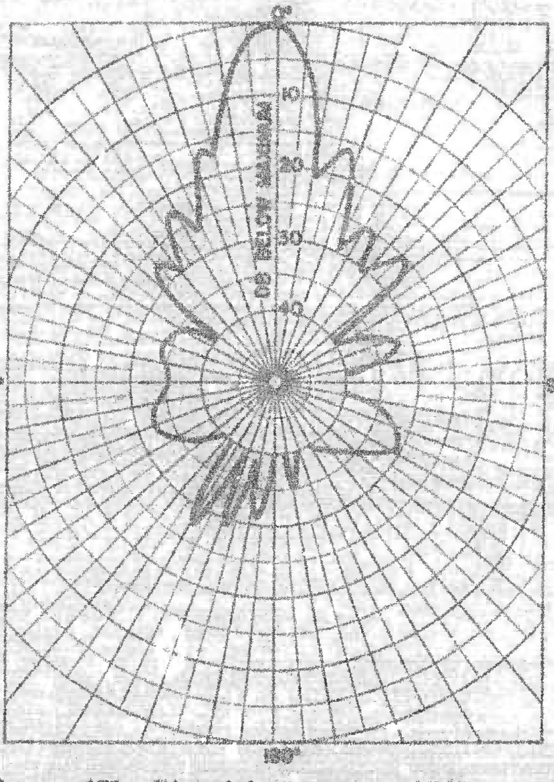


FIGURE 178. Directivity pattern, CBM 78156 projector at 23.95 kc. M/S unit. Directivity index = −24.2 db.

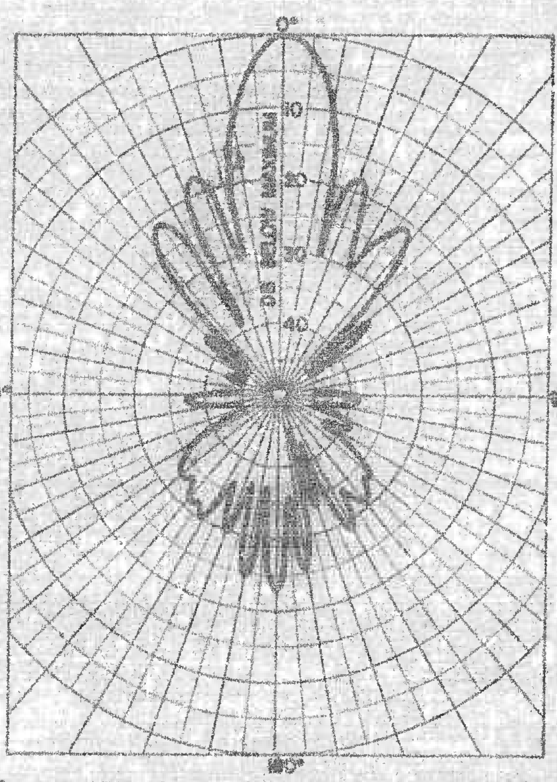


FIGURE 179. Directivity pattern, CBM 78156 projector at 23.95 kc. R/S unit. Directivity index = −23.8 db.

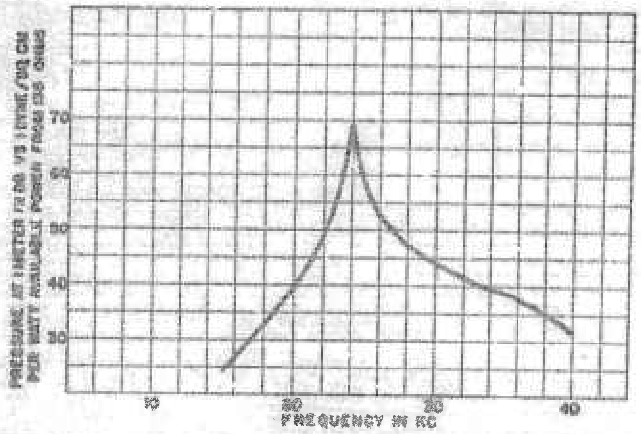


FIGURE 180. Transmitting response, CBM 78156 projector. M/S unit. Water temperature = 72 F. Q = 60.

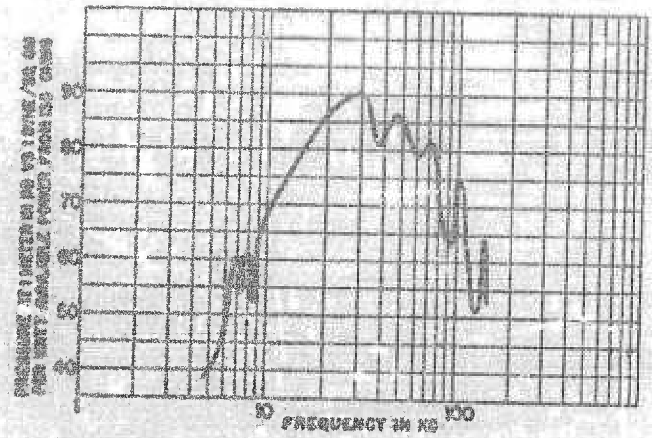


FIGURE 181. Transmitting response, CBM 78156 projector. R/S unit. Water temperature = 68 F.

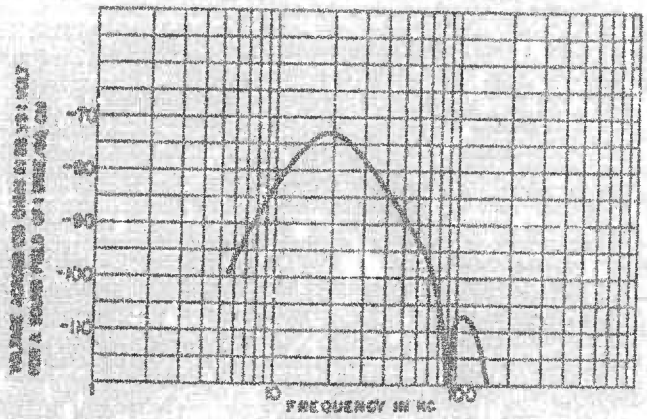


FIGURE 182. Receiving response, CBM 78156 projector. R/S unit. Water temperature = 60 F. Calculated threshold at 23.95 kc = −107.5 db vs 1 dyne/sq cm.

2.7.39

BTL QB-Type ADP Projector

Type: ADP Crystal.

Designer and Manufacturer: Bell Telephone Laboratories.

Reference: NDRC Report No. 6.1-sr1130-2131, February 1, 1945.[76]

Application: The QB-type ADP crystal projector was produced as an engineering model to serve as the bottom-side unit in the WFA-1 sonar equipment for submarines. The unit is intended for use both as an echo-ranging and as a listening transducer at supersonic frequencies.

Description: This projector is a modification of and is similar in external appearance to the 19-in. spherical QB-type projector. The active elements in this unit are ADP crystals. This projector is a four-wire unit split electrically for BDI or PAL operation.

Efficiency at 25 kc: —3.5 db vs ideal.

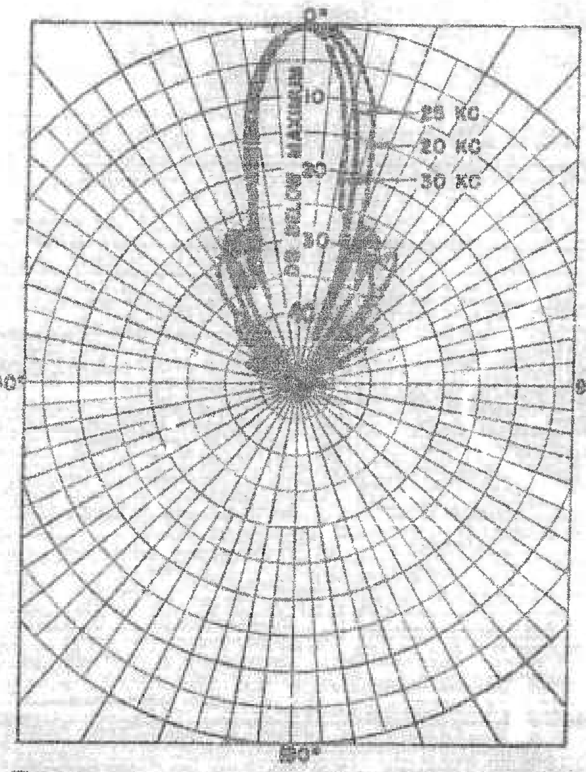


FIGURE 183. Directivity patterns, BTL QB-type ADP projector. Directivity index: at 20 kc = —22.4 db, at 25 kc = —24.1 db, at 30 kc = —25.6 db.

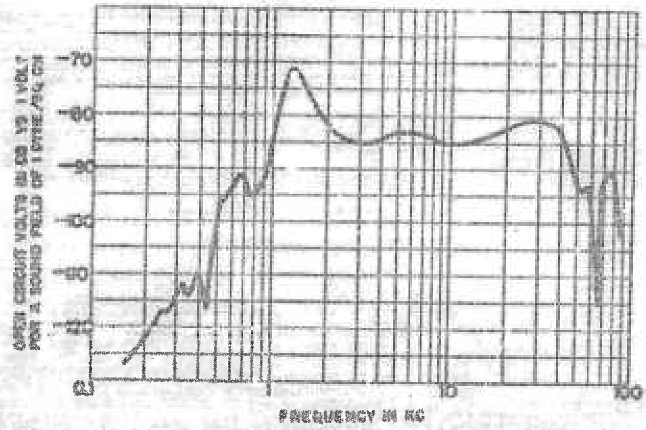


FIGURE 185. Receiving response, BTL QB-type ADP projector. Connected parallel aiding. Water temperature = 61 F. Calculated threshold at 25 kc = —105 db vs 1 dyne/sq cm.

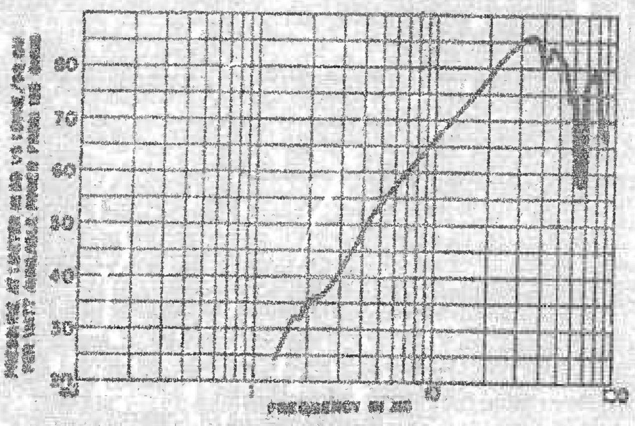


FIGURE 184. Transmitting response, BTL QB-type ADP projector. Connected parallel aiding. Water temperature = 61 F.

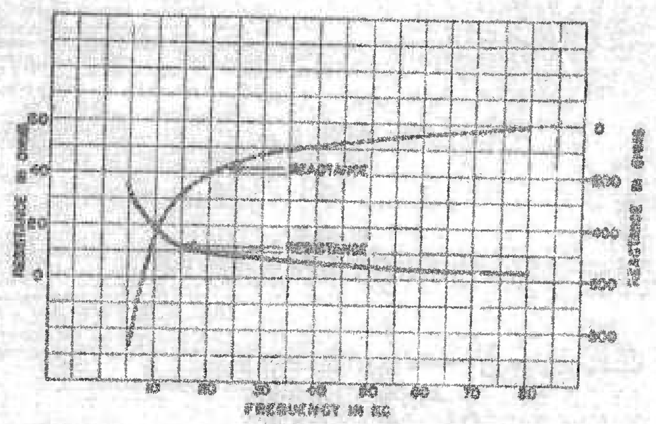


FIGURE 186. Impedance, BTL QB-type ADP projector.

2.7.10 Brush 14-Inch ADP Crystal Projector AX-63

Type: ADP Crystal.

Designer and Manufacturer: Brush Development Company.

Reference: NDRC Report No. 6.1-sr1130-1187, November 16, 1943.[58]

Application: The AX-63 is one of the first experimental-type echo-ranging units making use of ADP crystals in place of Rochelle salt crystals.

Description: The AX-63 projector consists of a number of ADP crystals in a cylindrical housing 14 in. in diameter and approximately 5 in. deep. The diaphragm face of the projector is rubber-covered. A ½-in. thick Corprene covering is placed over the back of the projector to reduce rear response.

Figures showing characteristics of AX-63 projector are included in Section 7.6.4.

Impedance at 24.2 kc: 202 — j968 ohms.

Efficiency: —2 db vs ideal.

2.7.41

NRL ADP Projector X-5

Type: ADP Crystal.

Designer: Naval Research Laboratory.

Reference: NDRC Report No. 6.1-sr1130-1988, January 25, 1945.[74]

Application: The X-5 projector is an experimental model embracing a modification of the QB-JK type 19-in. spherical projector. The active elements are ADP crystals instead of x-cut Rochelle salt crystals as used in the JK projector.

Description: The active elements of the X-5 projector consist of 1/8-in. wide strips of ADP crystals mounted on a steel plate. Fifty of these strips are mounted on each half of the diaphragm, and the two halves are separated by a cork strip. Electric connections are brought out from each half of the projector separately to adapt it for BDI. The projector is mounted in a standard JK spherical housing. The hemispherical window is made of sound-transparent rubber 1 in. thick, and the space behind is filled with air-free castor oil.

Efficiency at 24 kc: —2.4 db vs ideal.

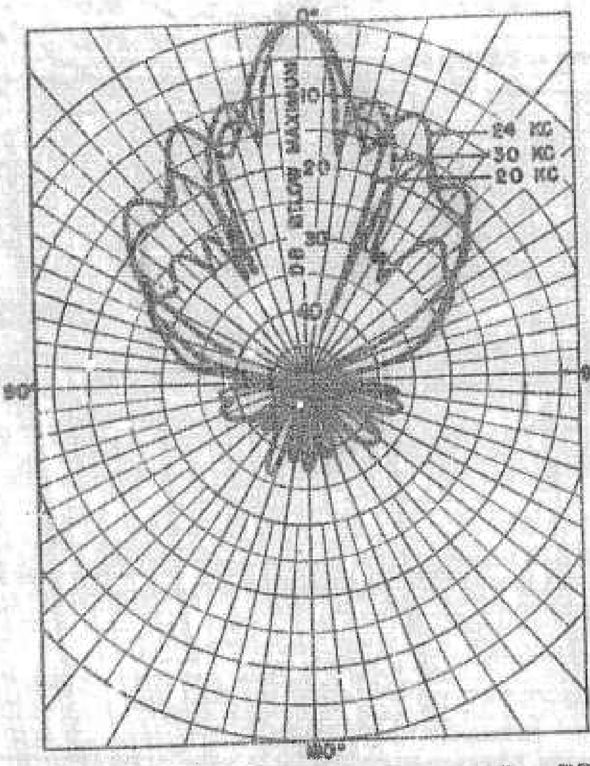


FIGURE 167. Directivity patterns, NRL ADP projector X-5. Directivity index at 24 kc = —20 db.

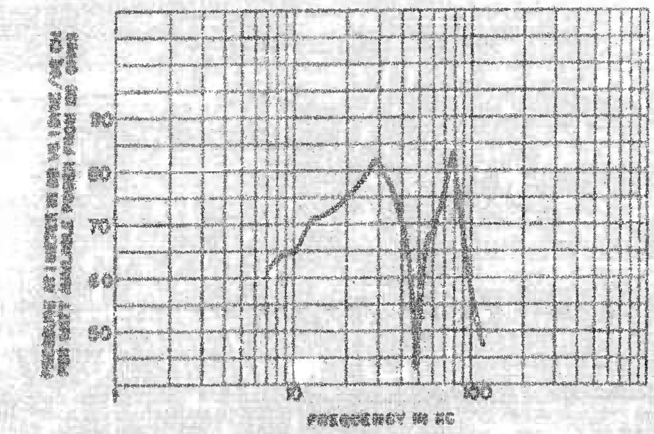


FIGURE 188. Transmitting response, NRL ADP projector X-6. Connected parallel aiding. Water temperature = 37 F.

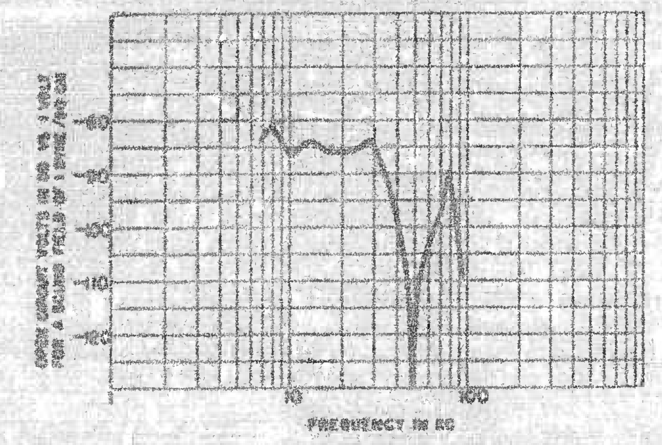


FIGURE 189. Receiving response, NRL ADP projector X-6. Connected parallel aiding. Water temperature = 37 F. Calculated threshold at 24 kc = —106 db vs 1 dyne/sq cm.

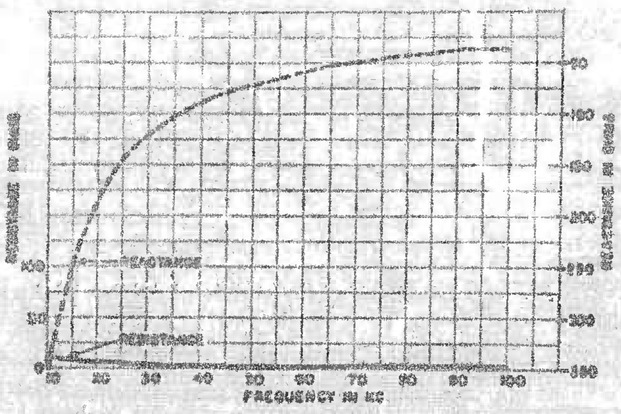


FIGURE 190. Impedance, NRL ADP projector X-5. Connected parallel aiding.

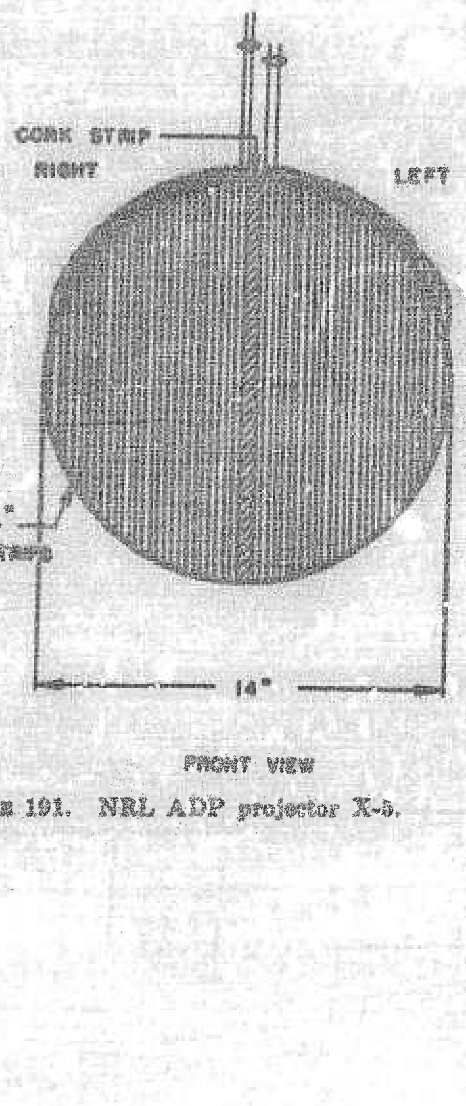


FIGURE 191. NRL ADP projector X-5.

2.7.42 NRL ADP Projector X-6

Type: ADP Crystal.

Designer: Naval Research Laboratory.

Reference: NDRC Report No. 6.1-sr1130-1988, January 25, 1945.[74]

Application: The X-6 projector is an experimental model embracing a modification of the QB-JK type 19-in. spherical projector. The active elements are ADP crystals instead of the Rochelle salt crystals as used in the JK projector.

Description: The X-6 projector employs a number of crystal blocks mounted individually on a bakelite backplate by means of brass studs. Two types of crystal blocks are used, one type consisting of eight 1¼x1x⅛ in. crystals, the other type being made up of sixteen 1¼x½x⅛ in. crystals. A total of 92 crystal blocks are used in the projector. The projector unit is mounted in a standard JK housing and is split for BDI operation.

Efficiency at 24 kc: —9.6 db vs ideal.

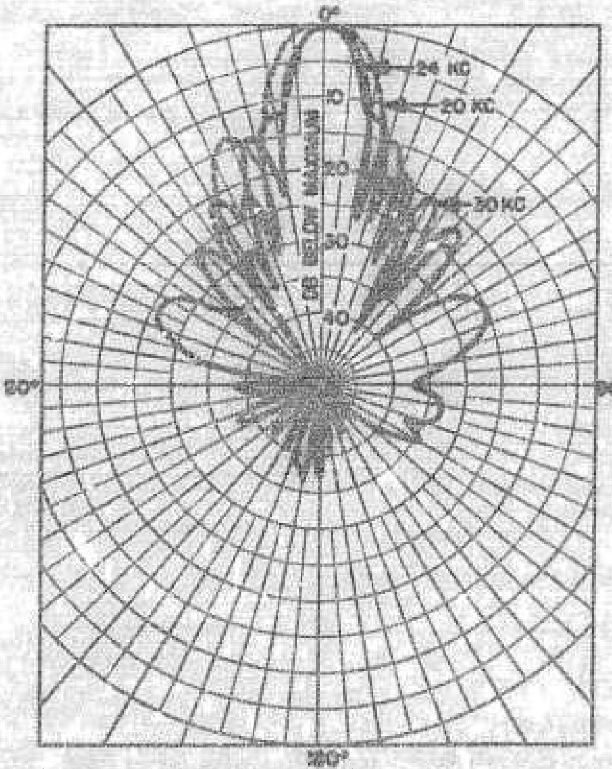


FIGURE 192. Directivity patterns, NRL ADP projector X-6. Directivity index at 24 kc = —24.3 db.

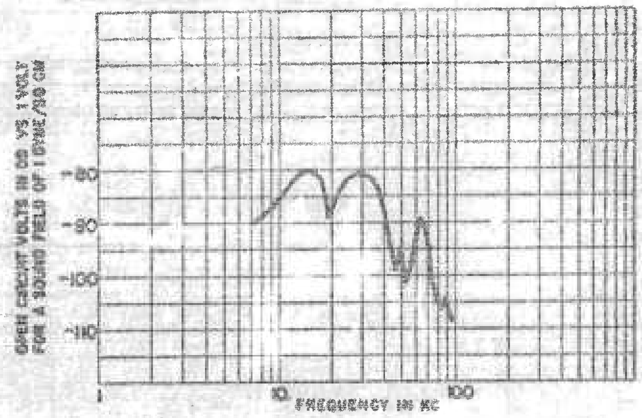


FIGURE 194. Receiving response, NRL ADP projector X-6. Connected parallel aiding. Water temperature = 37 F. Calculated threshold at 24 kc = —99 db vs 1 dyne/sq cm.

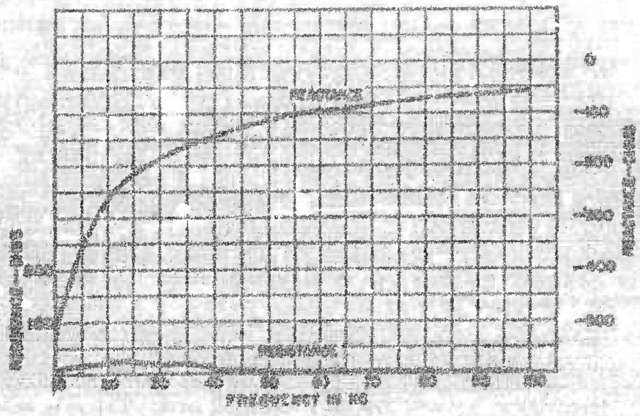


FIGURE 195. Impedance, NRL ADP projector X-6. Connected parallel aiding.

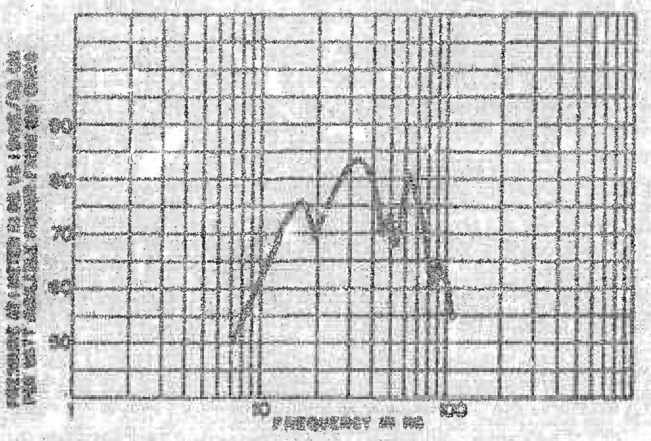


FIGURE 193. Transmitting response, NRL ADP projector X-6. Connected parallel aiding. Water temperature = 37 F.

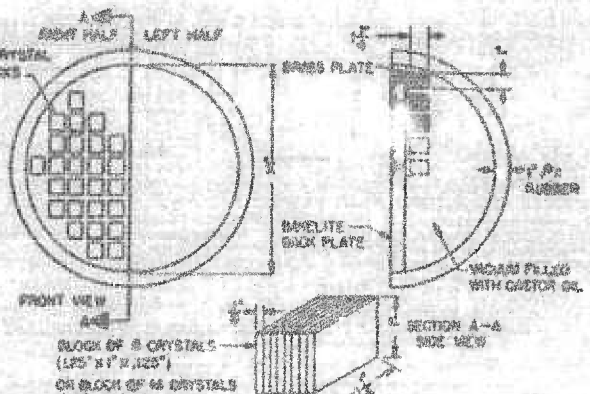


FIGURE 196. NRL ADP projector X-6.

2.7.48 RCA ADP Crystal Projector

Type: ADP Crystal.

Manufacturer: RCA Victor Division of the Radio Corporation of America.

Reference: NDRC Report No. 6.1-sr1130-1985, January 16, 1945.[72]

Application: This ADP projector is designed for use in sonar-ranging equipment. It is arranged for BDI operation. This projector is similar to the Brush Development Company AX-102-1 projector.

Description: The active elements of this projector are ADP crystals. The crystals are arranged in two diametrically opposite groups with separate electric connections to each group. Parallel-split connections to the two halves of the projector are provided for BDI operation. The projector is designed to operate from a transmitting source of 100 ohms at 100 w electric power input.

Efficiency at 22.3 kc: —1.2 db vs ideal.

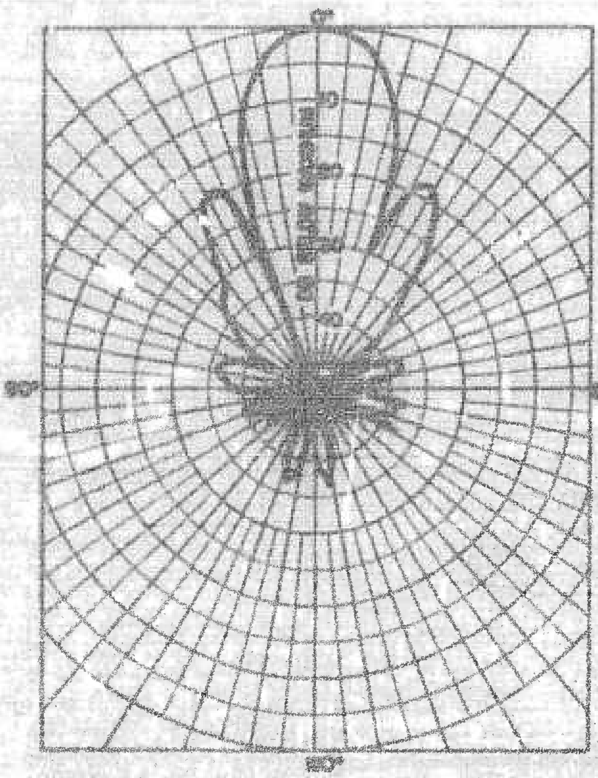


FIGURE 197. Directivity pattern, RCA ADP crystal projector at 22.3 kc. Directivity index = —20.4 db.

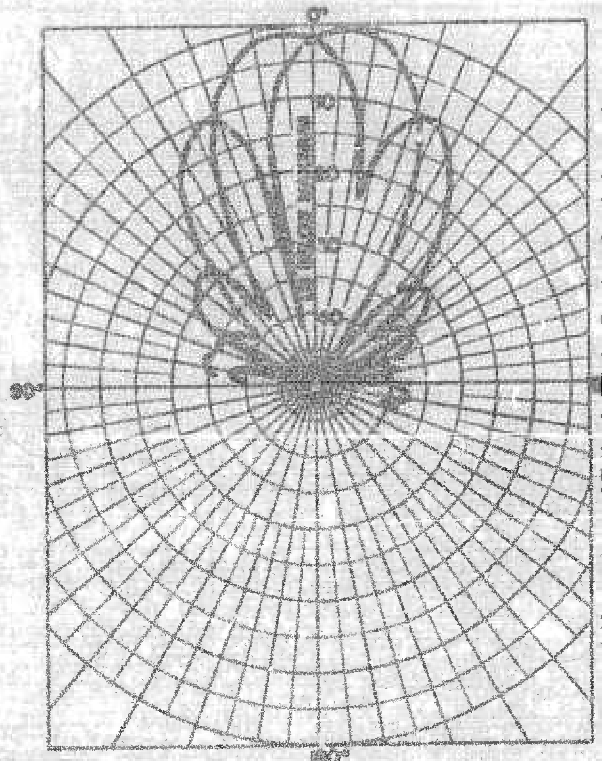


FIGURE 198. BDI patterns, RCA ADP crystal projector at 22.3 kc. Electrical phase shift = 74.3°.

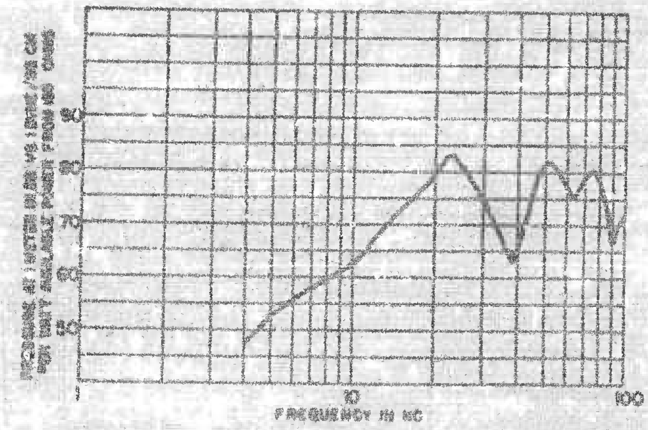


FIGURE 199. Transmitting response, RCA ADP crystal projector. Water temperature = 64 F. Q = 4.0.

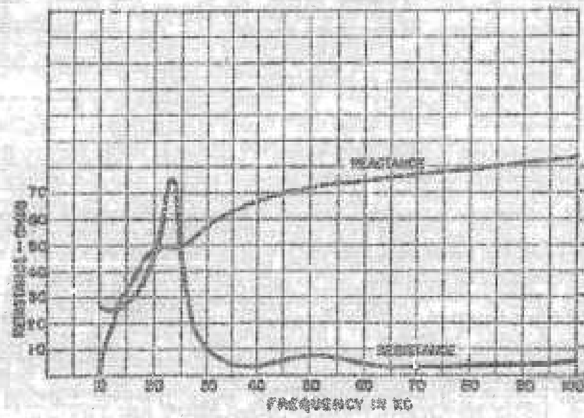


FIGURE 201. Impedance, RCA ADP crystal projector.

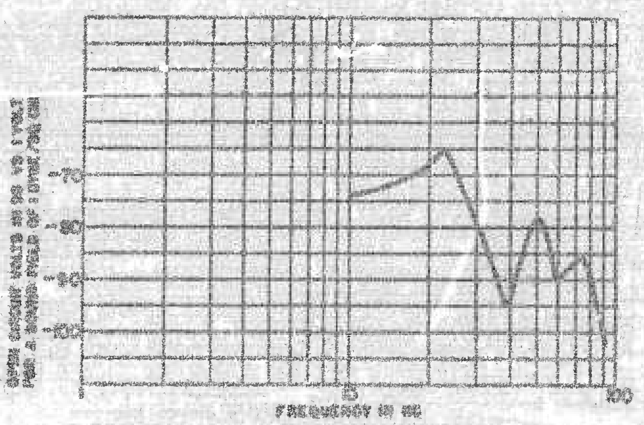


FIGURE 200. Receiving response, RCA ADP crystal projector. Water temperature = 64 F. Q = 4.5. Calculated threshold at 22.3 kc = −104 db vs 1 dyne/sq cm.

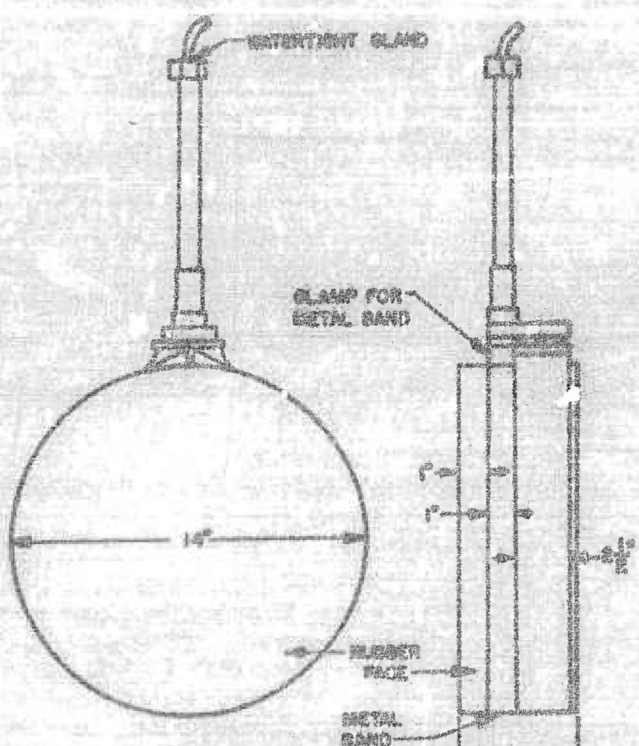


FIGURE 202. RCA ADP crystal projector.

2.7.44 Submarine Signal QB-Type ADP Crystal Projector SK 5982

Type: ADP Crystal.

Designer and Manufacturer: Submarine Signal Company.

Reference: NDRC Report No. 6.1-sr1130-1191, December 15, 1943.[61]

Application: This projector is an experimental unit designed for echo ranging and listening at supersonic frequencies.

Description: The SK 5982 projector is similar to the JK spherical projector except that ADP crystals are used instead of Rochelle salt crystals. The unit is split vertically for BDI operation.

Efficiency at 30 kc: —4.0 db vs ideal.

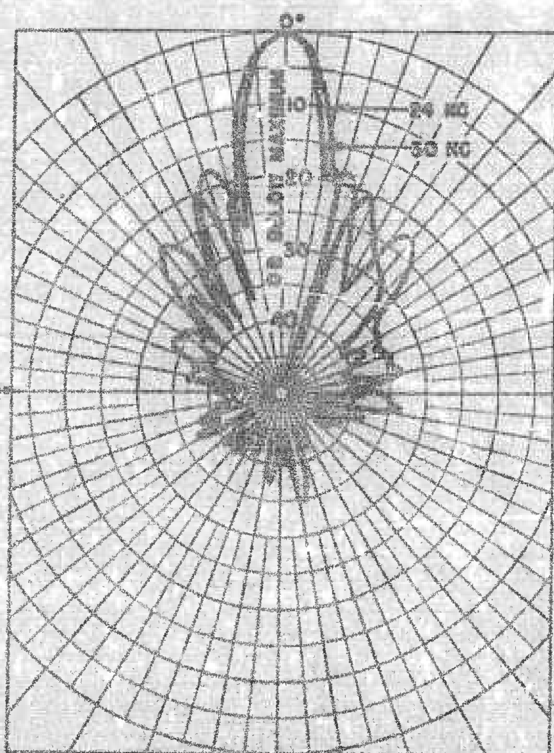


FIGURE 203. Directivity patterns, Submarine Signal QB-type ADP crystal projector SK 5982. Directivity index at 24 kc = —24.8 db, at 30 kc = —26.1 db.

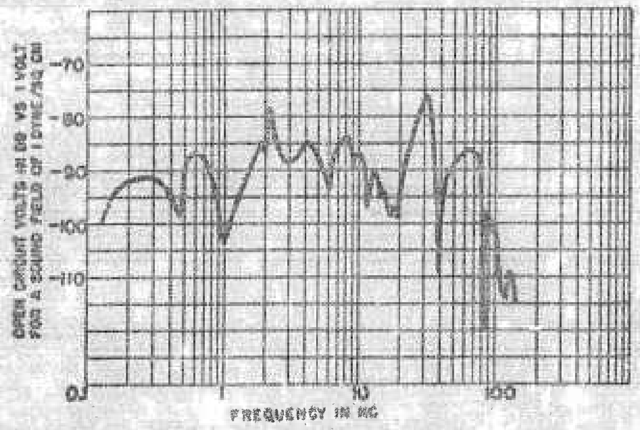


FIGURE 205. Receiving response, Submarine Signal QB-type ADP crystal projector SK 5982. Connected parallel aiding. Water temperature = 48 F. Calculated threshold at 30 kc = —97 db vs 1 dyne/sq cm.

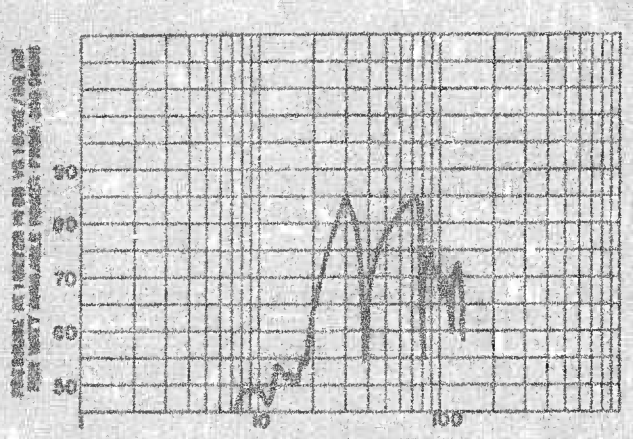


FIGURE 204. Transmitting response, Submarine Signal QB-type ADP crystal projector SK 5982. Connected parallel aiding. Water temperature = 48 F.

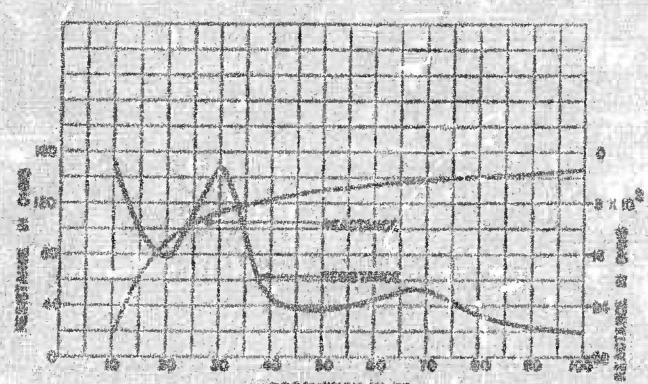


FIGURE 206. Impedance, Submarine Signal QB-type ADP crystal projector SK 5982. Connected parallel aiding.

8.7.46 "Football-Type" WFA-1 Topside Transducer

Type: ADP Crystal.

Designer and Manufacturer: Bell Telephone Laboratories, Type No. D171807.

Reference: NDRC Report No. 6.1-sr1130-2295, June 25, 1945.[79]

Application: The "football-type" transducer was produced as an engineering model to serve as the topside unit in the WFA-1 sonar equipment for submarines. The unit is intended for both echo ranging and listening at supersonic frequencies and for listening in the sonic range.

Description: The active elements of this transducer consist of ADP crystals. The transducer is made up of separate sections. The sonic listening elements are twenty-four 1x1x1.1 in. crystals encased in a cylindrical metal housing. These crystals are tuned by the mass and stiffness of the end plates of the cylindrical housing.

The section of the transducer designed for echo ranging and listening at supersonic frequencies consists of a group of crystal blocks each 0.5x0.5x0.66 in. mounted on a steel plate. The crystals in this group are tuned by resonators which are an integral part of the mounting plate. Separate electric connections are provided to the middle two horizontal rows of crystals in this group. These crystals comprise the maintenance of close contact [MCC] section. This grouping is designed to produce a broad vertical beam pattern and a sharp horizontal beam pattern.

All groups of crystals may be connected in parallel for listening in the sonic range. The two halves of all sections of the transducer are brought out separately to make them adaptable for use in BDI or in PAL circuits.

The crystal assembly is protected by a rubber diaphragm. The free space between the diaphragm and the crystals is vacuum-filled with oil. Weight of complete assembly: 1,000 lb.

Efficiency: Hydrophone (H) section at 6 kc: —27 db vs ideal.
Plate (P) section at 24 kc: —5 db vs ideal.
MCC section at 24 kc: —5.5 db vs ideal.
Entire Unit (S) at 6 kc: —22.5 db vs ideal.

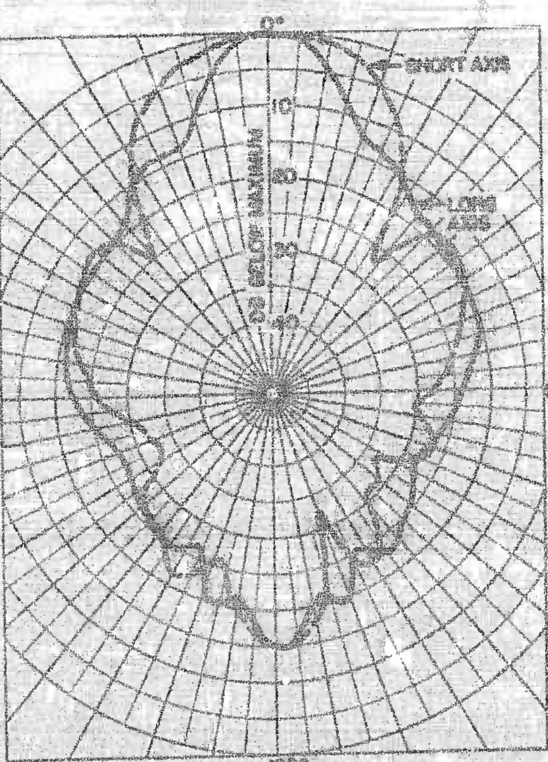


Figure 207. Directivity pattern, football-type WFA-1 topside transducer. Entire unit S at 6 kc. Directivity index = —13.5 db.

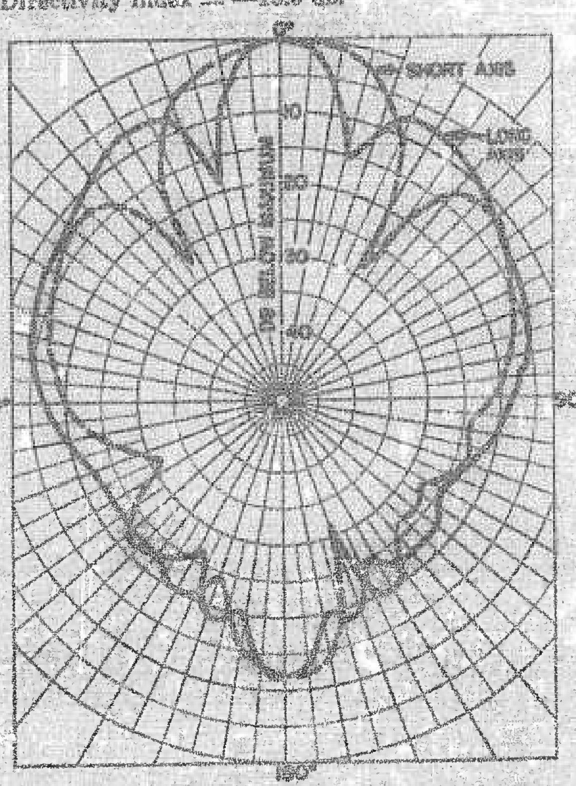


Figure 208. Directivity pattern, football-type WFA-1 topside transducer. Listening unit H at 6 kc. Directivity index = —20.0 db.

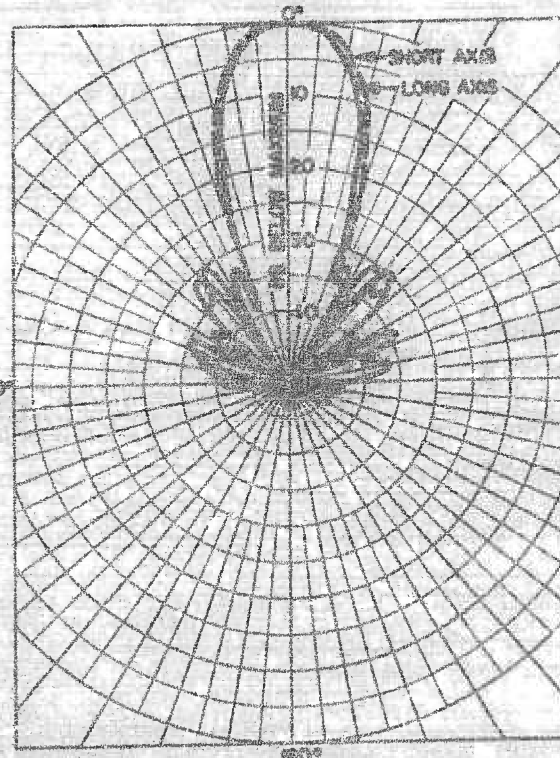


Figure 209. Directivity pattern, football-type WFA-1 topside transducer. Plate unit P at 24 kc. Directivity index = —21.5 db.

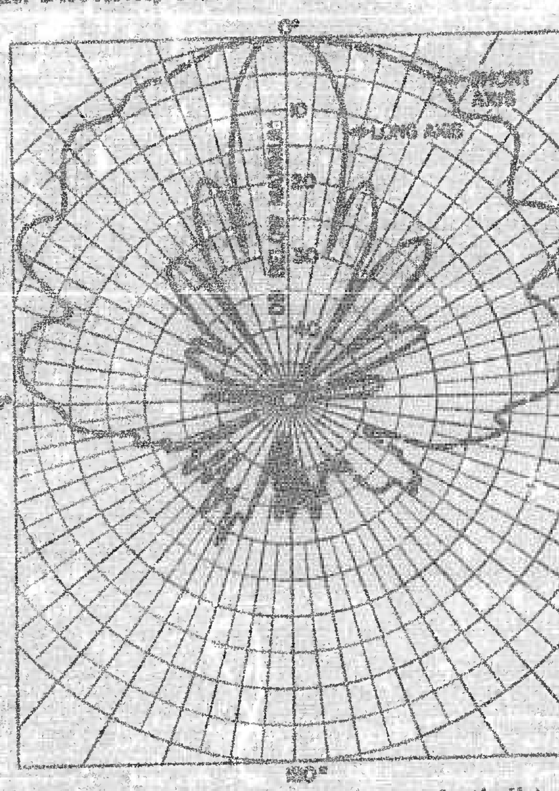


Figure 210. Directivity pattern, football-type WFA-1 topside transducer. Center unit MCC at 24 kc. Directivity index = —15.0 db.

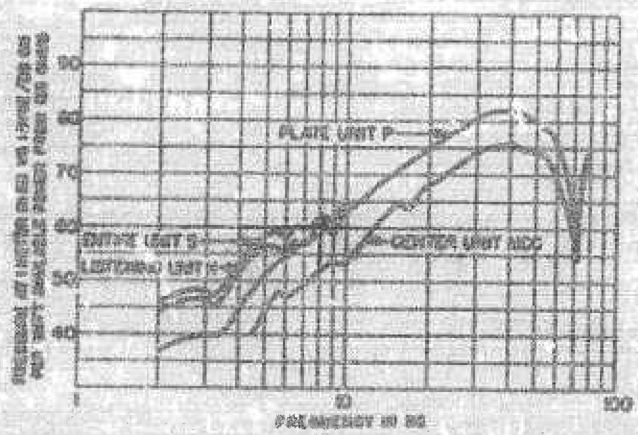


FIGURE 211. Transmitting response, football-type WFA-1 topside transducer. Water temperature = 60 F.

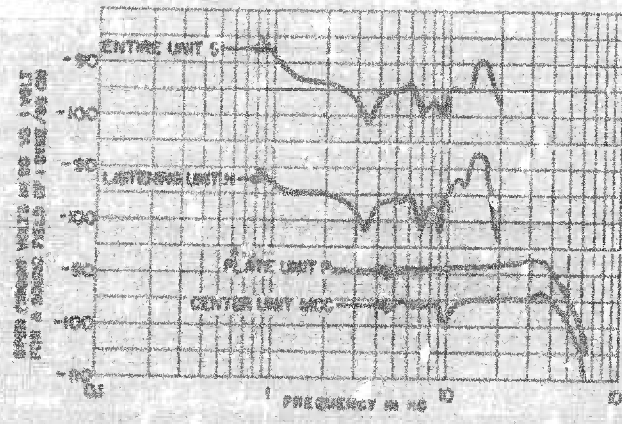


FIGURE 212. Receiving response, football-type WFA-1 topside transducer. Water temperature = 60 F. Calculated threshold: entire unit S at 6 kc = —92 db vs 1 dyne/sq cm, listening unit H at 6 kc = —91 db vs 1 dyne/sq cm, plate unit P at 24 kc = —98 db vs 1 dyne/sq cm, center unit MCC at 24 kc = —92 db vs 1 dyne/sq cm.

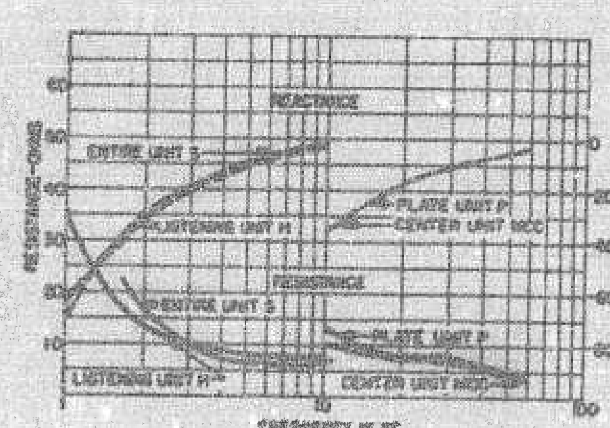


FIGURE 213. Impedance, football-type WFA-1 topside transducer.

FIGURE 214. Football-type WFA-1 topside transducer.

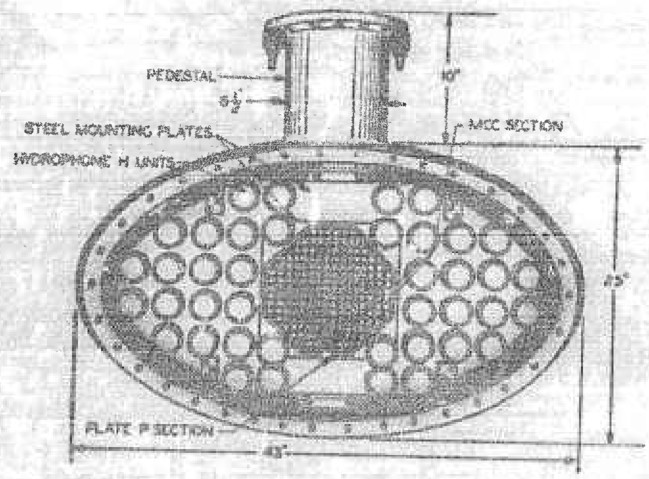


FIGURE 215. Football-type WFA-1 topside transducer with rubber cover removed.

2.7.46 Harvard Sword Arm Depth Angle Transducer

Type: Magnetostriction.

Designer: Harvard University Underwater Sound Laboratory.

Reference: NDRC Report No. 6.1-sr1130-1826, August 28, 1944.[70]

Application: This transducer is an experimental unit intended for use in determining the range and depth of underwater objects such as submarines.

Description: The sword arm depth angle transducer consists of 32 permanent-magnet polarized stacks of annealed nickel mounted in a bronze casting. The laminated stacks are Cycle-Welded to the rubber nosepiece. The transducer is intended to be mounted vertically, and the housing is streamlined. Shading to reduce the height of the side lobes is accomplished by the number of turns of wire on the stacks, those stacks located near the middle of the transducer having more turns than the stacks located farther away. The transducer is split for BDI operation.

Efficiency: —4.7 db vs ideal.

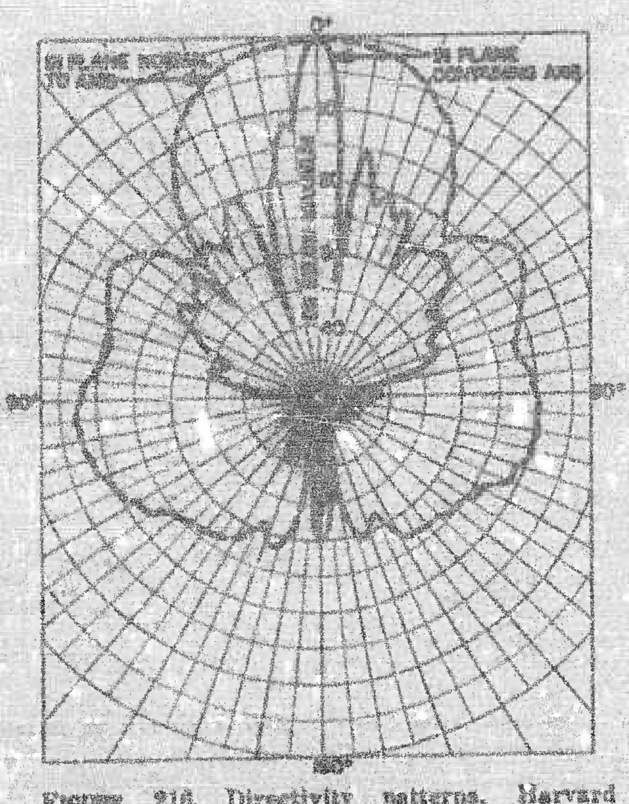


Figure 216. Directivity patterns, Harvard sword arm depth angle transducer at 60 kc.

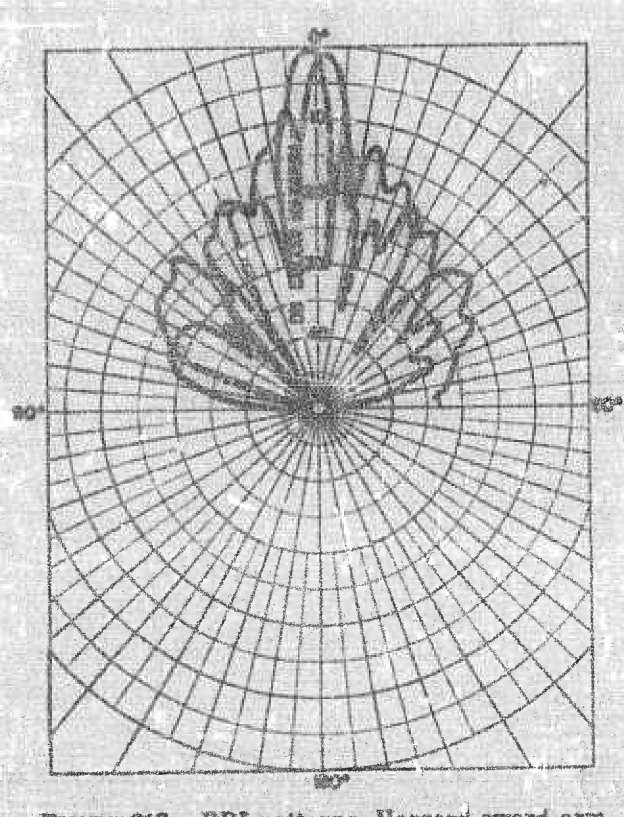


Figure 217. BDI patterns, Harvard sword arm depth angle transdt cer at 60 kc. Electrical phase shift = 60°.

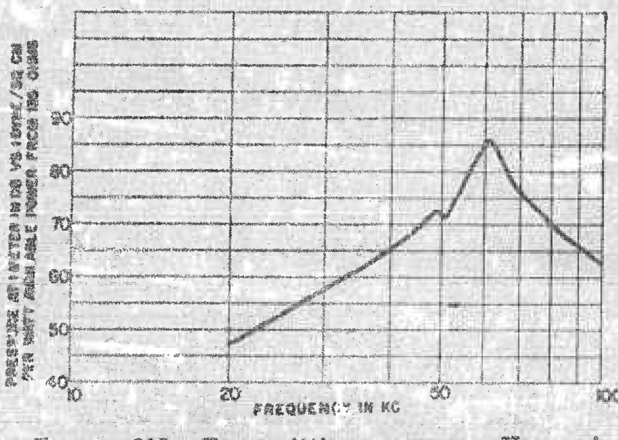


FIGURE 218. Transmitting response, Harvard sword arm depth angle transducer. Connected parallel aiding. Q = 11.5. Water temperature = 68 F.

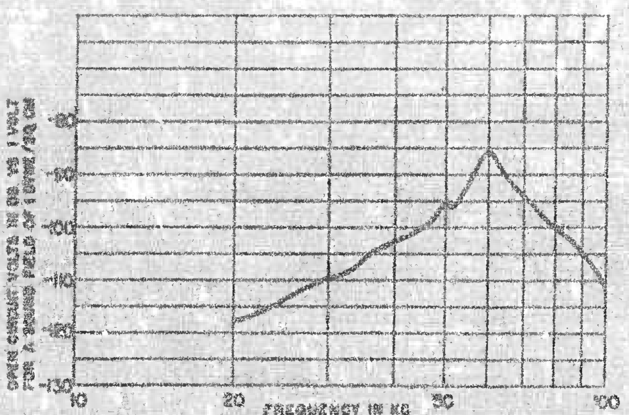


FIGURE 219. Receiving response, Harvard sword arm depth angle transducer. Connected parallel aiding. Water temperature = 68 F. Q = 11.5. Calculated threshold at 60 kc = —89 db vs 1 dyne/sq cm.

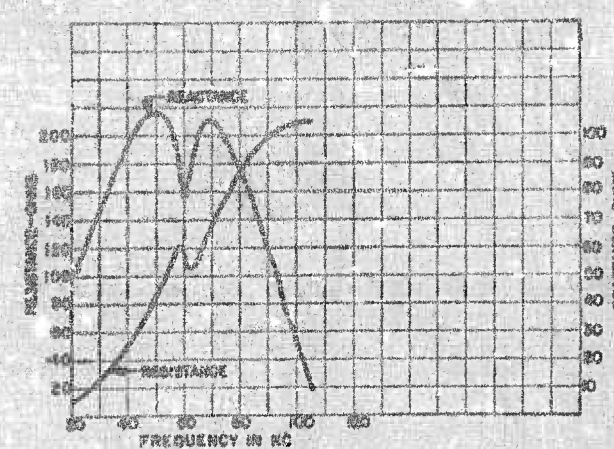


FIGURE 220. Impedance, Harvard sword arm depth angle transducer. Connected parallel aiding.

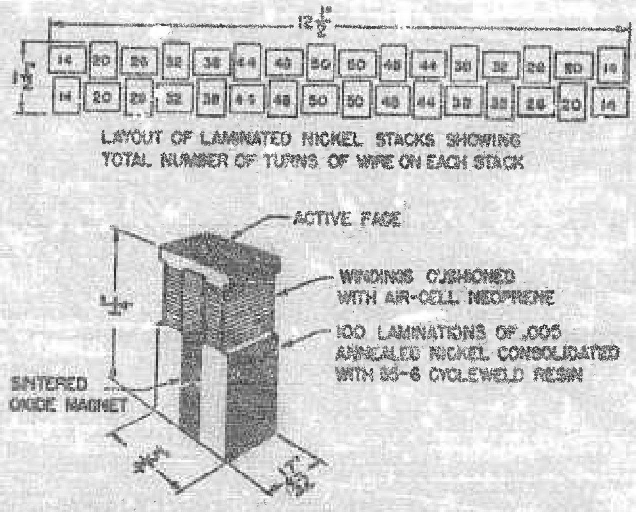


FIGURE 221. Harvard sword arm depth angle transducer.

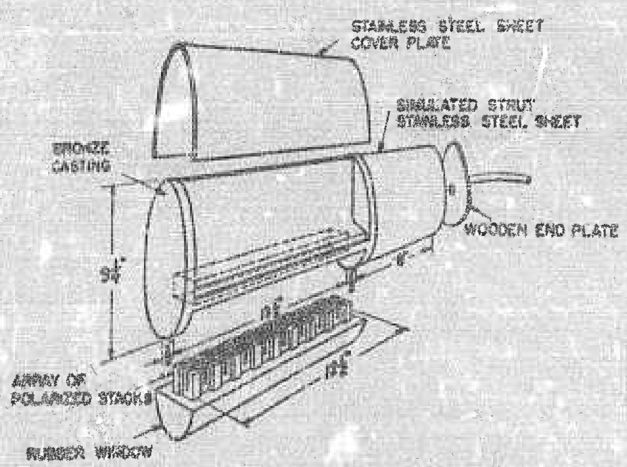


FIGURE 222. Permanent magnet polarized stack for Harvard sword arm transducer.

2.7.47 HP-4 Laminated Stack Transducer

Type: Magnetostriction.

Designer: Harvard University Underwater Sound Laboratory.

Reference: NDRC Report No. 6.1-sr1130-1826, August 28, 1944.[70]

Application: The HP-4 transducer is an experimental unit.

Description: The HP-4 transducer consists of a consolidated stack of annealed laminations with permanent, sintered oxide magnet. The laminations are Cycle-Welded to the inside of a rectangular face 2⅛x3⅜ in. A sheet-metal housing fits over the motor unit. The housing is lined with air-sealed neoprene, and a rubber sealing tape is employed to fasten the housing to the motor unit.

Efficiency: —4.7 db vs ideal.

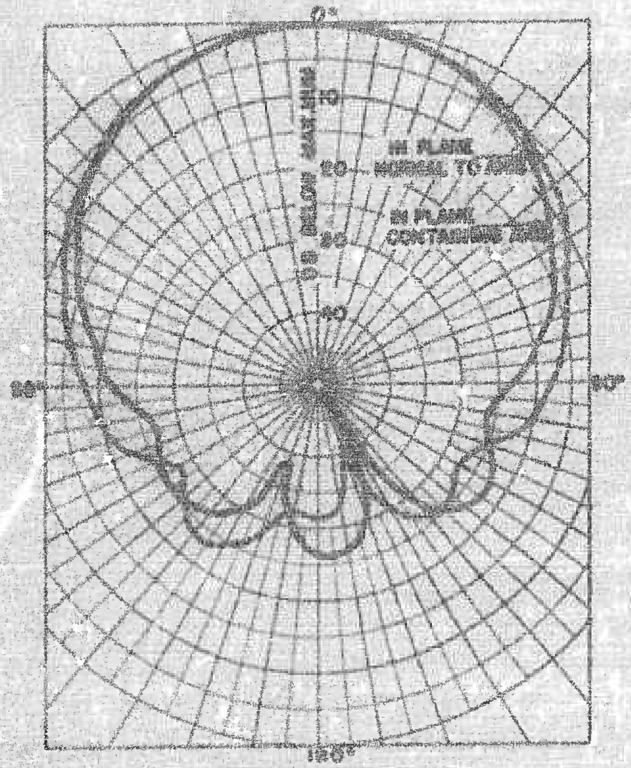


FIGURE 223. Directivity patterns, HP-4 laminated stack transducer at 27 kc. Directivity index = —9.8 db.

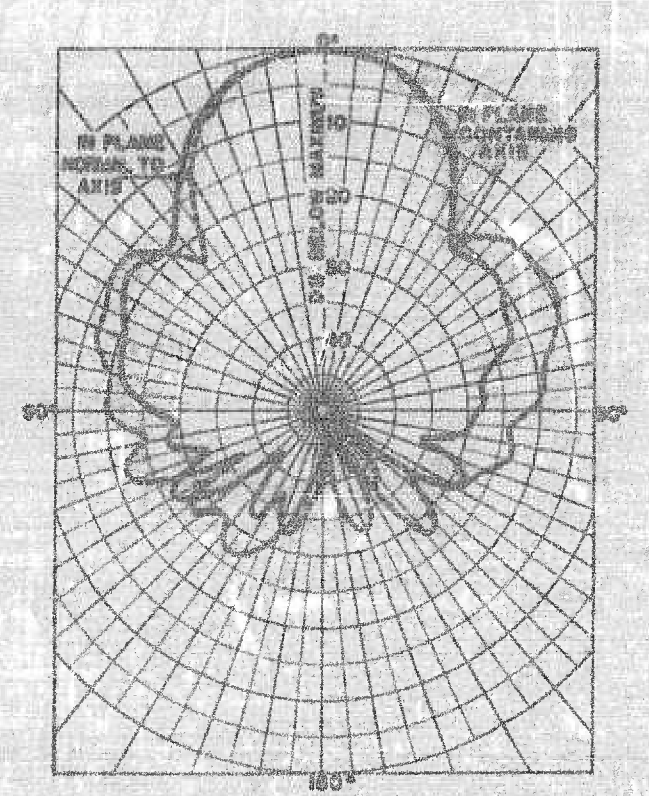


FIGURE 224. Directivity patterns, HP-4 laminated stack transducer at 52.5 kc.

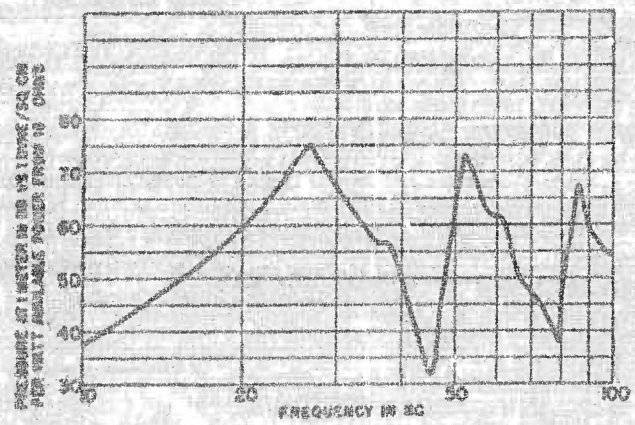


FIGURE 225. Transmitting response, HP-4 laminated stack transducer. Water temperature = 68 F.

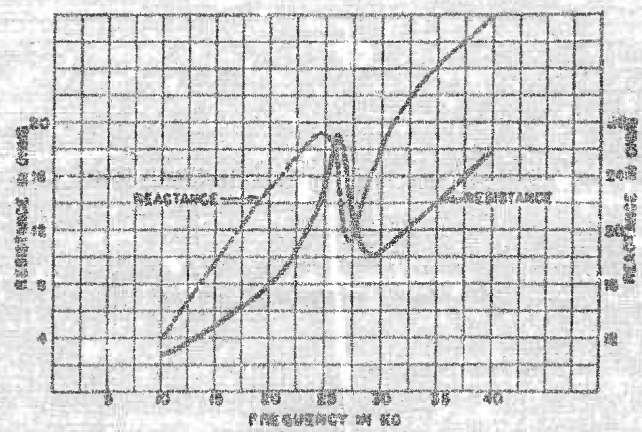


FIGURE 227. Impedance, HP-4 laminated stack transducer.

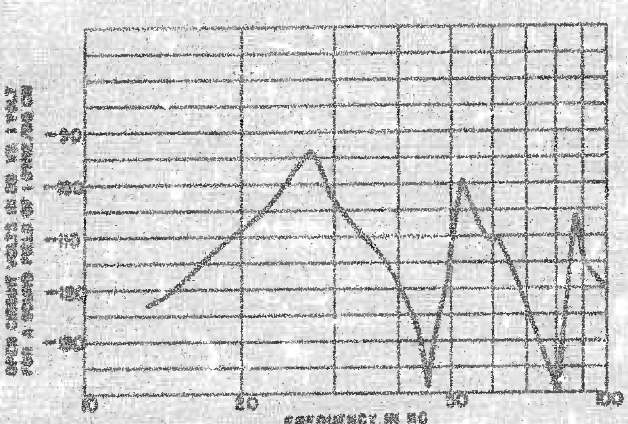


FIGURE 226. Receiving response, HP-4 laminated stack transducer. Water temperature = 68 F. Calculated threshold at 27 kc = −89 db vs 1 dyne/sq cm.

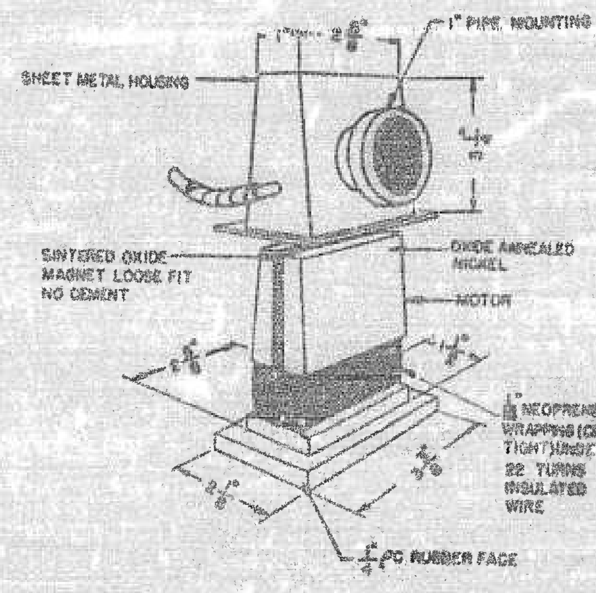


FIGURE 228. HP-4 laminated stack transducer.

2.7.46 Submarine Signal Projector SK 4044

Type: Electrodynamic.

Designer and Manufacturer: Submarine Signal Company.

Reference: NDRC Report No. C4-sr20-202, September 3, 1942.[44]

Application: The SK 4044 projector is an experimental-type echo-ranging projector.

Description: The SK 4044 projector is an electrodynamic-type unit containing a permanent magnet. The diaphragm of this unit is 6 in. in diameter. Maximum allowable input power is 20 w. The projector is tuned to resonate at about 15 kc by means of condensers built into the unit.

Impedance at 15 kc: $86.6 - j19.8$ ohms.

Efficiency at 15 kc: -3 db vs ideal.

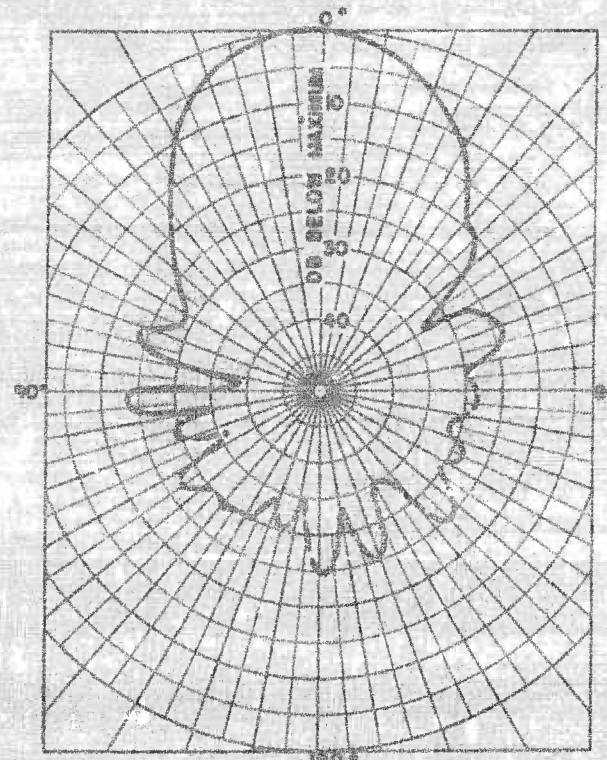


FIGURE 229. Directivity pattern, Submarine Signal projector SK 4044 at 15 kc. Directivity index = —13.3 db.

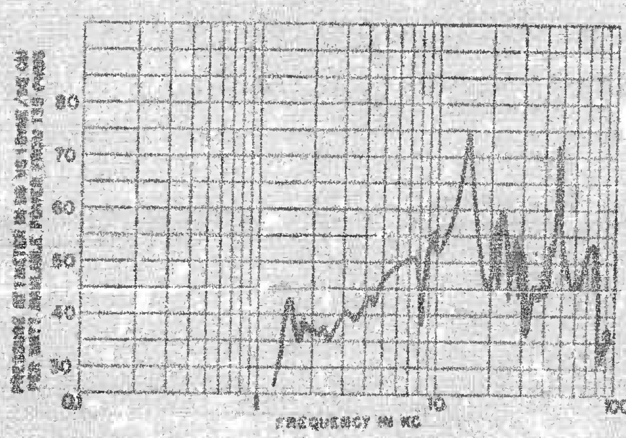


FIGURE 230. Transmitting response, Submarine Signal projector SK 4044. Water temperature = 90 F. Q = 20.

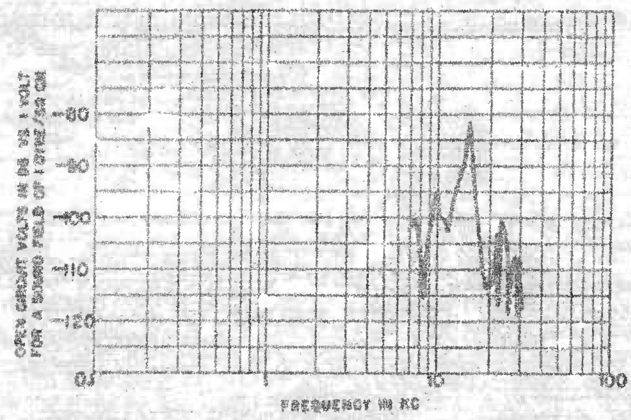


FIGURE 231. Receiving response, Submarine Signal projector SK 4044. Water temperature = 90 F. Q = 20. Calculated threshold at 15 kc = —94 db vs 1 dyne/sq cm.

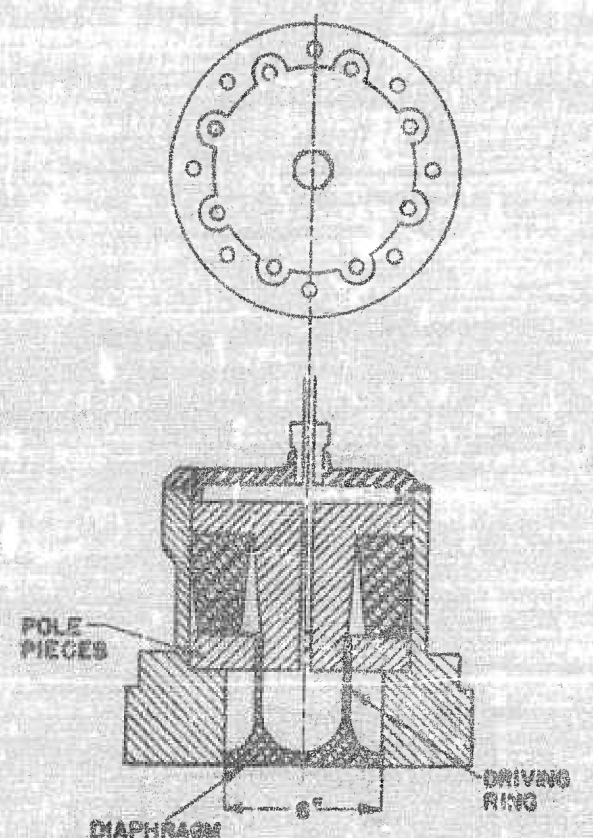


FIGURE 232. Submarine Signal projector SK 4044.

2.7.49 Submarine Signal Projector SK 4610C

Type: Magnetostriction.

Designer and Manufacturer: Submarine Signal Company.

Reference: NDRC Report No. C4-sr20-201, August 29, 1942.[79]

Application: The SK 4610C is an experimental depth-sounding type projector.

Description: This projector is a laminated permanent-magnet type magnetostriction unit in a reflector-type housing. The calibration data for this projector is given for the unit tuned by means of a capacity of 0.045 μf in series with the projector winding.

Impedance at 18.5 kc: $82 + j10$ ohms.

Efficiency at 18.5 kc: -8 db vs ideal.

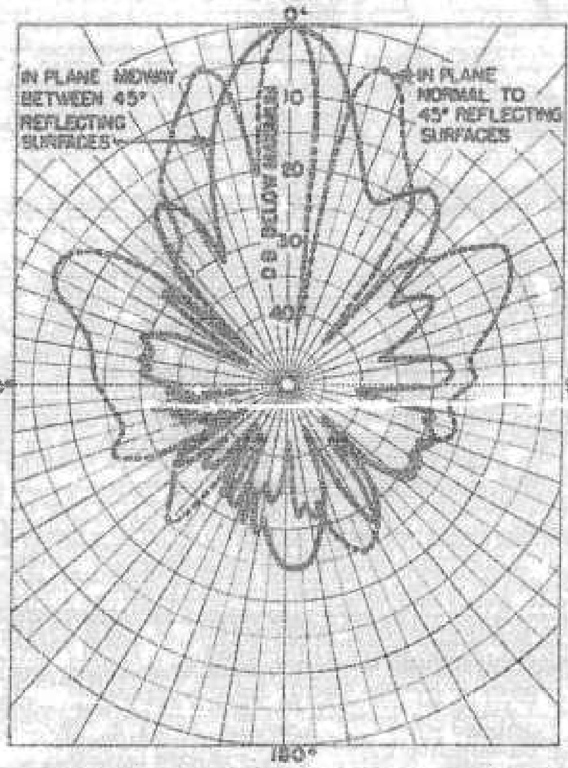


FIGURE 233. Directivity patterns, Submarine signal projector SK 4610C at 18.4 kc. Directivity index = —20 db.

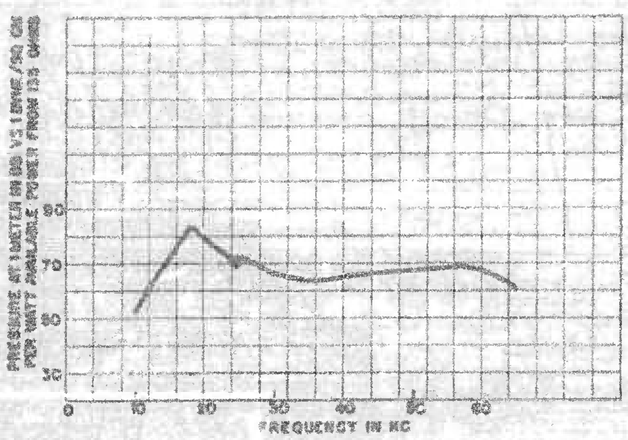


FIGURE 234. Transmitting response, Submarine Signal projector SK 4610C. Water temperature = 80 F.

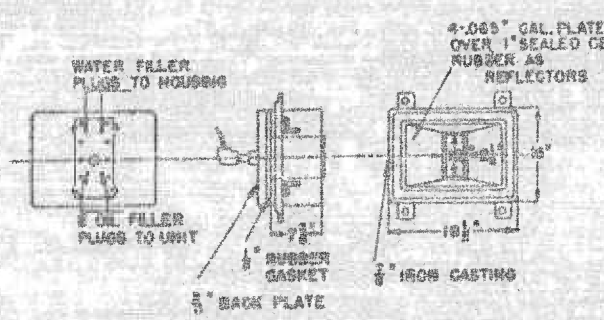


FIGURE 235. Submarine Signal projector SK 4610C.

Chapter 3

DOMES

A GENERAL DISCUSSION of the use and the acoustic design of domes has been given.[a] It will be recalled here that, in general, a streamlined dome is necessary for an echo-ranging or listening device in order to minimize the noise caused by its passage through the water, and the resultant turbulence and cavitation about its active face. The dome, of course, should be of optimum hydrodynamic shape; mechanically, it should have sufficient strength to resist pressure and drag, and should be constructed of a noncorrosive sea-resistant material. Finally, the dome should be acoustically transparent, causing as little disturbance as possible in the response and directivity of the enclosed acoustic device.

To be acoustically transparent, the dome must fulfill the following two main requirements.

1. It must have a small transmission loss.[b]
2. It must not introduce large specular reflection side lobes into the directivity pattern of the enclosed transducer.

In addition, the dome should not distort the enclosed transducer's directivity pattern by multiple reflections, e.g., appreciably raise its rear response, nor should it appreciably alter the width of the transducer's main lobe or increase the magnitude of the side lobes already present in the directivity pattern. Finally, internal reflections from the dome should not greatly alter the transducer's radiation impedance. All of these last effects are, however, quite small in modern, well-designed domes.

The various acoustical disturbances introduced by domes, such as specular reflections and transmission losses, are, of course, interrelated. In general, a dome which introduces small specular reflections also causes small transmission losses. Moreover, because the change in the transducer's radiation impedance is small, its total power output is unaffected by enclosing it within a dome; also, "true absorption" of sound within the dome wall is negligible for metal domes. As a consequence, the energy which is removed by the dome wall from the impinging transducer beam, and which constitutes the transmission loss, is redistributed in directions other than the original direction of incidence; in particular, the major portion of this energy is concentrated in the direction of specular reflection.[c] This redistribution has the effect of increasing the value of the directivity index; it can be shown that:[d]

Transmission loss in db = db change in transducer directivity index introduced by the dome.

Expressions have been obtained theoretically, and generally verified experimentally, for the magnitudes of both the transmission loss and the specular reflection induced by a dome of given material, wall thickness, and dimensions on an enclosed transducer of given frequency, directivity, and position within the dome.[d] These expressions indicate that the transmission loss of a dome depends only on the thickness and density of the dome wall and on the frequency, increasing as any of these quantities increase. On the other hand, the specular reflection, in addition to increasing with increasing dome-wall thickness and density and with the frequency, also depends on the horizontal and, particularly, the vertical curvature of the dome wall and on the directivity and location of the enclosed transducer. The specular reflection is greatly minimized by increasing the vertical dome-wall curvature; thus torpedo-shaped domes with a large vertical as well as a moderate horizontal curvature give much smaller specular reflections than straight-sided domes of the same wall thickness and density but possessing horizontal curvature only.[e]

[a] See STR Division 6, Volume 10, Chapter 9, and the references quoted therein.

[b] The transmission loss gives the reduction in the magnitude of the axis response of a transducer upon dome enclosure.

[c] The magnitude of the additional side lobes introduced by the dome into the directivity pattern, e.g., the additional rear response, also increases as the transmission loss increases.

[d] See STR Division 6, Volume 10, Chapter 9.

[e] See Table 1 and Figures 12 to 44; also STR Division 6, Volume 10, Chapter 9.

Since both the transmission and specular reflection decrease with the dome-wall thickness and density, dome design has tended to employ wall materials as thin and as light as possible, consistent with sufficient mechanical strength and general seaworthiness. Thus, while most dome walls or "acoustic windows" have thus far been constructed from corrosion-resisting steel, other materials, namely, aluminum, various plastics, and stiff rubber strengthened mechanically by an expanded metal-grid structure, have all been used experimentally.[f]

The first two of these materials are excellent acoustically; however, their seaworthiness is questionable. Although it is claimed that aluminum corrodes easily in sea water, proper treatment of the metal may render it salt-water resistant."[5] Plastics are subject to aging and temperature effects. Stiff rubber is acoustically but little inferior to standard 0.020-in. steel,[f] and is probably preferable from the standpoint of seaworthiness.

In the attempt to achieve minimum dome-wall or acoustic window thickness consistent with mechanical strength, it has been found possible, in straight-sided domes at least, to use quite thin walls (0.020 in. to 0.030 in.) supported by an expanded metal-grid structure.[h] Such an arrangement is acoustically preferable to using thicker walls.[g,4] The acoustic window may also be reinforced by aluminum ribs (British design, see Figure 10), or corrugated sheet construction may be used. The latter[g] has the additional virtue of decreasing the magnitude of the specular reflection (though not of the transmission loss) to values smaller than those obtained with a noncorrugated wall of the same thickness.[g,4] Finally, torpedo domes, because of their shape, have greater mechanical strength for a given thickness than straight-sided domes.

Table 1 refers to representative domes at present in use in the U. S. Navy for housing echo-ranging projectors, as well as to several experimental models. The domes are classified according to shape, longest dimension, wall (acoustic window) material and thickness, type of filling, and mode of suspension. The acoustic properties of the domes obtained from USRL calibrations, and summarized in terms of their transmission loss and specular reflection at specified angles and frequencies, are also given.

It is seen that the transmission loss, which depends only on the wall thickness and density and on the frequency, is in general small, particularly for the 0.020-in. to 0.030-in. domes. Specular reflection, which depends on the wall thickness, wall material, and frequency, is also strongly affected by the horizontal and, particularly, vertical curvature of the walls. The torpedo-shaped, vertically-curved domes, even though equipped with walls much thicker than the acoustic windows of the straight-sided domes (for example, QBF: 0.020 in., vs QCU-1: 0.050 in.) have, nevertheless, comparable and often smaller specular reflections. The numerical values of the transmission loss and specular reflection of all these domes are in general agreement with theoretical expectations.[i]

Figures 1 to 11 are photographs and diagrams of several representative and most widely used domes listed in Table 1 (photographs of QGA, QBF, QCU-1; diagrams of QGA, QBF, British, WEA-1, QCU-1, QC spherical). These photographs and diagrams show details of the mechanical construction and layout of the domes, for example, acoustic window wall, expanded metal-grid structure, position of reinforcing ribs, position of projector and baffle.[j] Explanatory captions are included.

Figures 12 to 44 show directivity patterns of the bare projector and of the enclosed projectors with 0, 30, 45, and 60 degrees between the projector and dome axes. Patterns are given for the QCU-1, QCU-2, and WEA-1 torpedo-shaped, and the QBF, 54-in., and QGA straight-sided domes. The patterns are obtained by keeping the angle between projector and dome axis fixed, and rotating both simultane-

[f] The rubber is vulcanized to both sides of the grid structure.

[g] See Table 1.

[h] See Figures 2 and 3 for photographs showing the grid structure.

[i] See STR Division 6, Volume 10, Chapter 9.

[j] The baffles used in domes to shield the projector from propeller noise (see STR Division 6, Volume 10, Chapter 9) are shown in Figures 2 and 3 for the QBF and QGA domes. These baffles consist of a reflecting steel plate (≅ ¼ in. thick) facing the screws attached to a wire mesh castor oil absorbing assembly (≅ 3 in. thick), with a front rubber cover acting to absorb any stray sound from the dome nose.

5

TABLE 1

Name	Shape	Longest dimension (in.)	Material of wall or acoustic window	Wall or acoustic window thickness (in.)	Type of filling	Mode of suspension	Transmission loss* (db) at specified frequency	Specular reflection* (db) below main beam at 30°, 45°, 60°, between dome and projector axes at specified frequency	References, NDRC Report No.
QCU-2	Torpedo or fish; horizontally and vertically curved; approximately ellipsoidal	50	Stainless corrosion-resisting steel	0.062	Free-flooding	Retractable (into a sea chest)	0.5 at 25 kc	13.0, 12.5, 18.5 at 25 kc	6.1-sr1130-2140[103]
QCU-1	"	42	"	0.050	"	"			
WEA-2	"	42	"	0.050	"	"	1.0 at 25 kc	16.0, 18.5, 20.0 at 25 kc	6.1-sr1130-1379[88]
WEA-1	"	31	"	0.062	Oil, sodium chromate solution, free-flooding	"	0.75 at 25 kc	22.0, 19.5, 23.0 at 25 kc	6.1-sr20-798,[46] 946[91]
							1.0 at 25 kc	13.3, ..., 15.0 at 25 kc	6.1-sr20-878[89]
WEA-1	"	31	"	0.062	Oil	"	~0 at 25 kc	10.5, 10.0, 13.0 at 25 kc†	6.1-sr20-667[89]
WEA-1	"	31	"	0.020	Free-flooding	"	0.2 at 25 kc	24.5, 24.2, 27.0 at 25 kc	6.1-sr20-951,[88] 1192[93]
WEA-1	"	31	"	0.040	"	"	0.5 at 25 kc	22.2, ..., 24.0 at 25 kc	6.1-sr20-1192[93]
WEA-1	"	31	Aluminum	0.038	"	"	0.5 at 25 kc	27.5, ..., 31.8 at 25 kc	6.1-sr20-1192[93]
QBF	Straight-sided; approximately elliptical cross section	50	Stainless corrosion-resisting steel, reinforced by expanded metal-grid structure	0.020	"	"	0.6 at 25 kc	19.0, 18.0, 16.0 at 25 kc	6.1-sr1130-1634[88]
54-in.	"	54	"	0.020	"	"	~0.5 at 25 kc	13.0, 14.0, 16.7 at 25 kc	6.1-sr1130-1628,[99] 887[96]
54-in.	"	54	"	0.030	"	"	~0.6 at 25 kc	....., 13.2, ... at 25 kc	6.1-sr1130-1628,[99] 887[96]
54-in.	"	54	Rubber reinforced by expanded metal-grid structure	.....	"	"	~0.5 at 25 kc	13.8, 12.6, 16.7 at 37 F at 25 kc; 15.0, 13.8, 15.7 at 63 F at 25 kc	6.1-sr1130-1082[101]
British type 883A	"	54	Stainless corrosion-resisting steel, reinforced by aluminum ribs	0.020	"	Welded to ship's side	2.6 at 25 kc	....., 15.0, ... at 25 kc	6.1-sr20-153,[82] 289[97]
Sub. Sig. British type	Straight-sided; approximately elliptical cross-section	54	Stainless corrosion-resisting steel, reinforced by pressed steel channels	0.020	"	"	5.5 at 25 kc	....., 14.0, ... at 25 kc	6.1-sr20-153[82]
Early Budd	"	54	Stainless corrosion-resisting steel, reinforced by steel bars	0.125	"	"	3.5 at 25 kc	....., 9.0, ... at 25 kc	6.1-sr20-153[82]
57-in. Budd	"	57	Stainless corrosion-resisting steel, reinforced by expanded metal-grid structure	0.020	"	"	0.7 at 25 kc	15.6, 13.8, 15.5 at 25 kc	6.1-sr20-948[97]
NRL Corrugated	"	57	Stainless corrosion-resisting steel, corrugated horizontally	0.025	"	"	1.9 at 25 kc	16.6, 15.8, 21.0 at 25 kc	6.1-sr20-1194[93]
100-in. QGA	"	100	Stainless corrosion-resisting steel, reinforced by expanded metal-grid structure	0.020	"	"	0.2 at 15 kc 0.6 at 30 kc	17.7, 17.1, 21.5 at 15 kc 16.7, 12.7, 15.5 at 30 kc	6.1-sr20-953,[89] 1626[97] 6.1-sr20-953,[89] 1626[97]
QC Spherical	Spherical	18½	Stainless corrosion-resisting steel	0.040	Free-flooding ethylene glycol	Retractable (into a sea chest)	0.55, 3.15 at 25 kc 2.8, 12.6 at 70 kc	....	6.1-sr1130-1196[93]
									Miscellaneous dome reports 6.1-sr20-954,[90] 959[92] 6.1-sr1130-1368[94] 6.1-sr1130-1635[102] 6.1-sr1130-2143[104]

* Where several reports are quoted, measurements on the same dome with transducers of similar directivity are all averaged together.

† The rather high specular reflection in this case is due not only to the large wall thickness (0.062 in.), but also to the excessively wide beam of the projector employed.[94]

ously relative to a fixed sound source. These patterns show the magnitude of the specular reflections[a] and of other disturbances introduced by the various domes into the directivity pattern. The other disturbances involve multiple reflections, increase in rear response, broadening of the main lobe, etc.; they are comparatively small in practically all cases.

Figures 45 to 47 show transmission loss versus frequency curves taken at 0° between dome and projector axes for representative straight-sided and torpedo domes (QGA, QBF, and QCU-2). It is seen that the transmission loss in general increases with frequency.

Figures 48 and 49 show transmission loss versus orientation of projector relative to dome axis, i.e., for different angles of sound incidence for the straight-sided QBF and the torpedo-shaped WEA-1 domes. It is seen that the transmission loss is practically independent of the angle of incidence, at least within the range used, i.e., up to angles of 45°. Theory and experiment both indicate, however, that the transmission loss becomes larger at higher frequencies and oblique angles of incidence, i.e., angles greater or equal to 75°.[i] The large losses exhibited in the diagrams at angles ≅ 180° between dome and projector axes are due to the effect of the shielding baffle within the dome.

[a] The values of the specular reflections included in Table 1 are obtained from these patterns. It may be noted that the specular reflections usually occur at angles with respect to the dome axis which are expected from the value of angle of incidence; the latter is determined by the angle between the dome and projector axes and by the geometry of the dome.[94]

[i] Thus the comparatively large transmission loss of the corrugated dome is due to sound incident obliquely on part of the corrugation. Further, in Figure 47 for the transmission loss of the QCU-2 dome, the curve referring to the projector tilted through 75° (large angle of incidence on dome wall) exhibits the large loss at the higher frequencies.

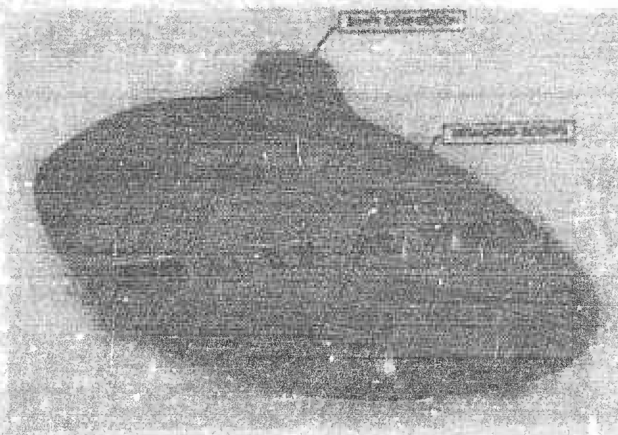


FIGURE 1. QCU dome, Navy type No. CUB-75223.

FIGURE 2. View of QBF dome.

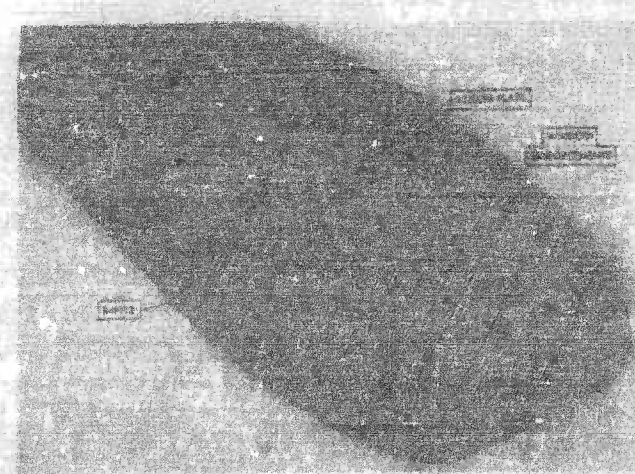


FIGURE 3. 100-in. QGA dome, Navy type No. CUB-78201, top view.

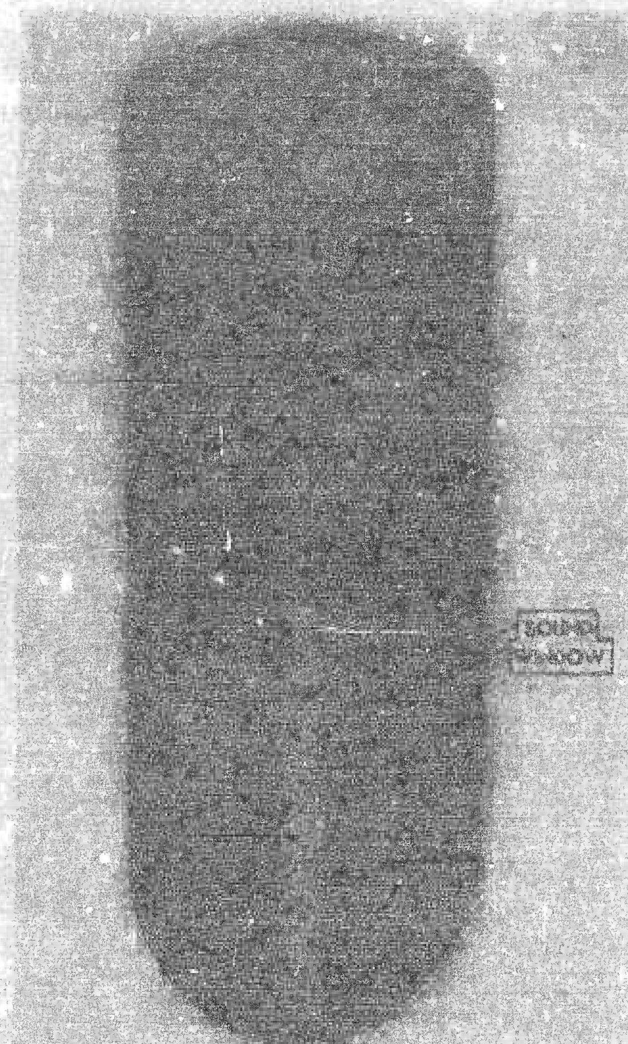


FIGURE 4. 100-in. QGA dome, Navy type No. CUB-78201, forward view.

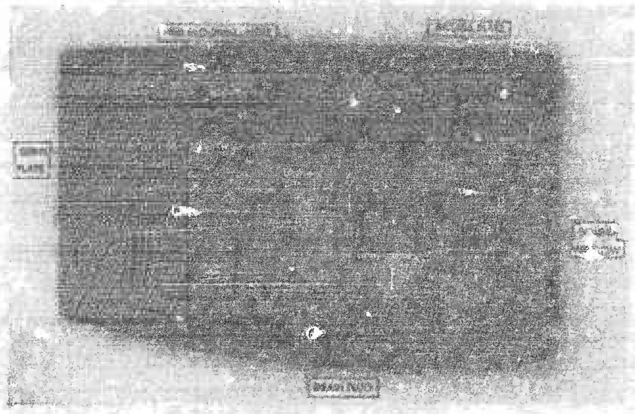


FIGURE 5. 100-in. QGA dome, Navy type No. CUB-78201, starboard view.

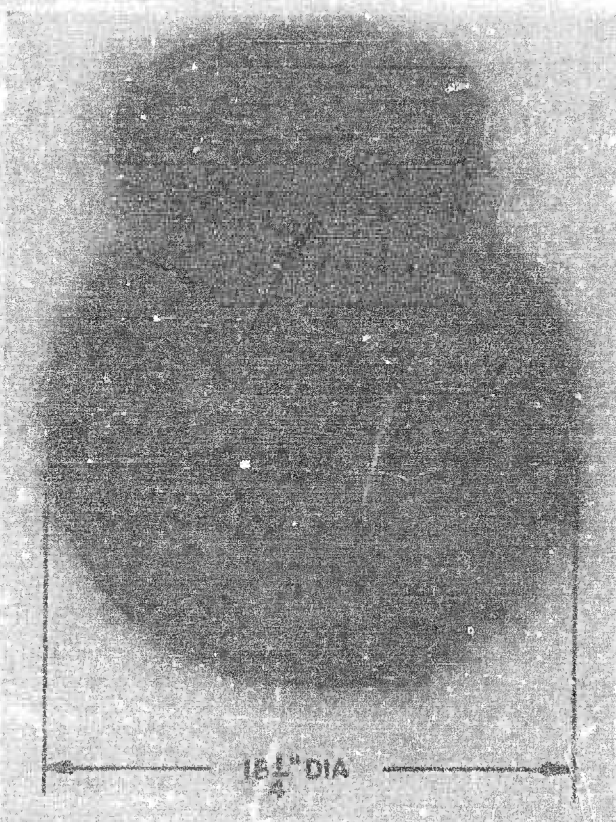


FIGURE 6. QC spherical dome.

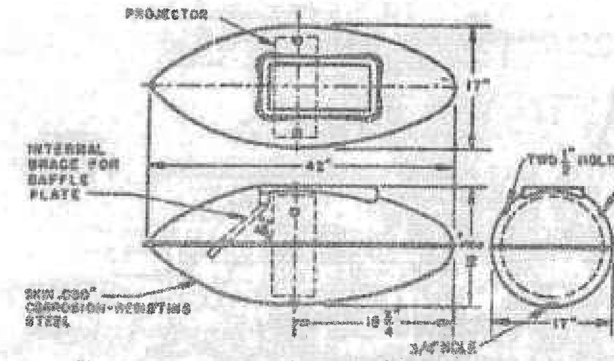


FIGURE 7. 42-in. QCU torpedo-shaped dome.

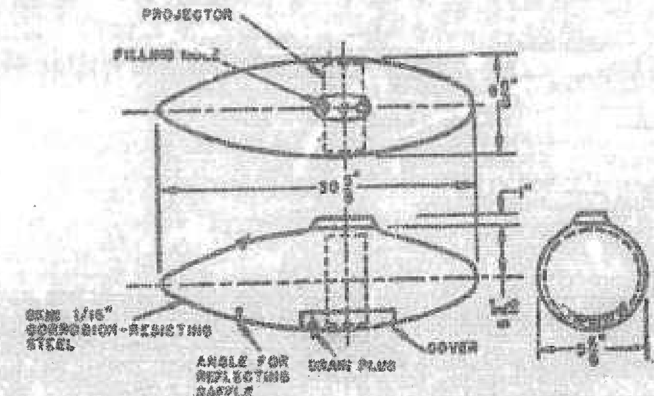


FIGURE 8. WEA-1 torpedo-shaped dome.

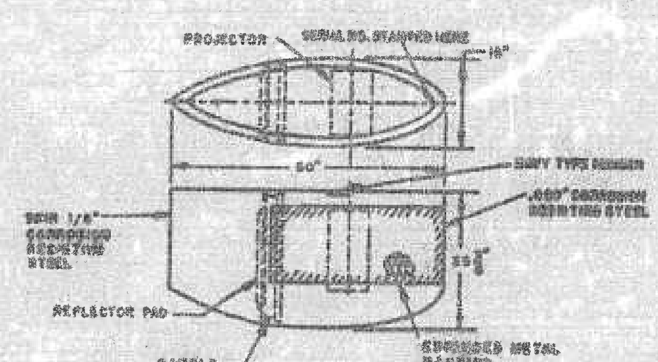


FIGURE 9. 50-in. QBF straight-sided dome.

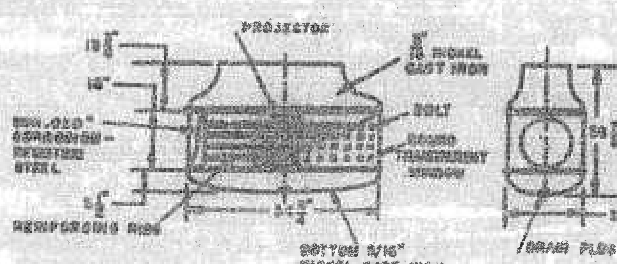


FIGURE 10. 54-in. British type straight-sided dome.

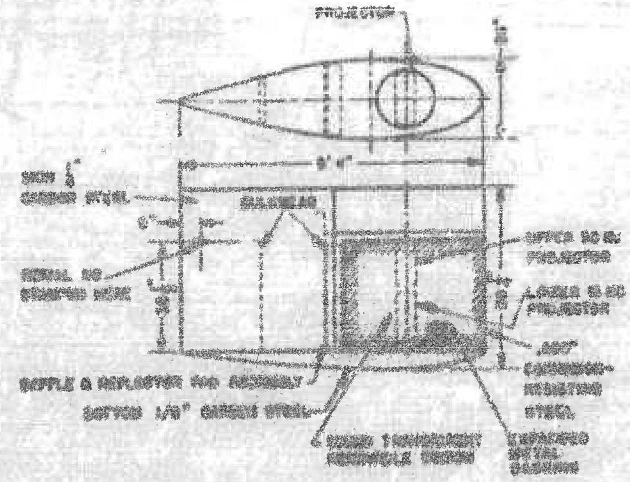


FIGURE 11. 160-in. QGA straight-sided dome.

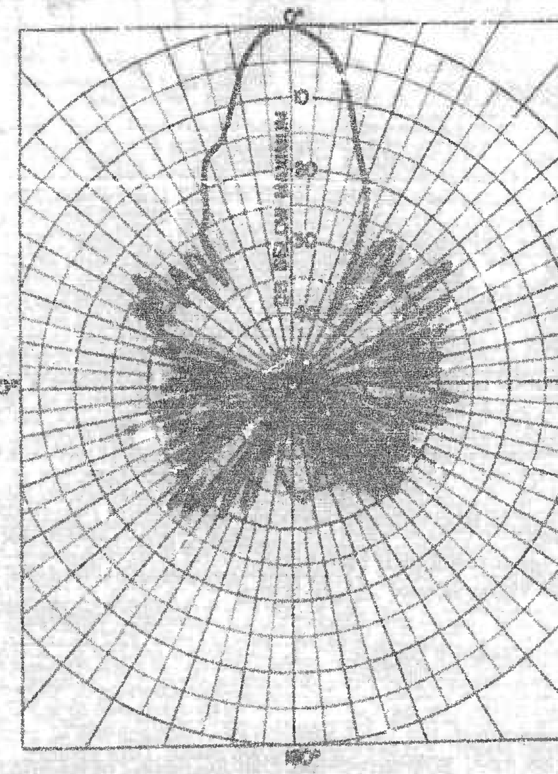


FIGURE 13. Receiving directivity pattern: in QCU-1 dome with baffle. Unit at 0° with respect to dome axis. Projector and dome rotated together.

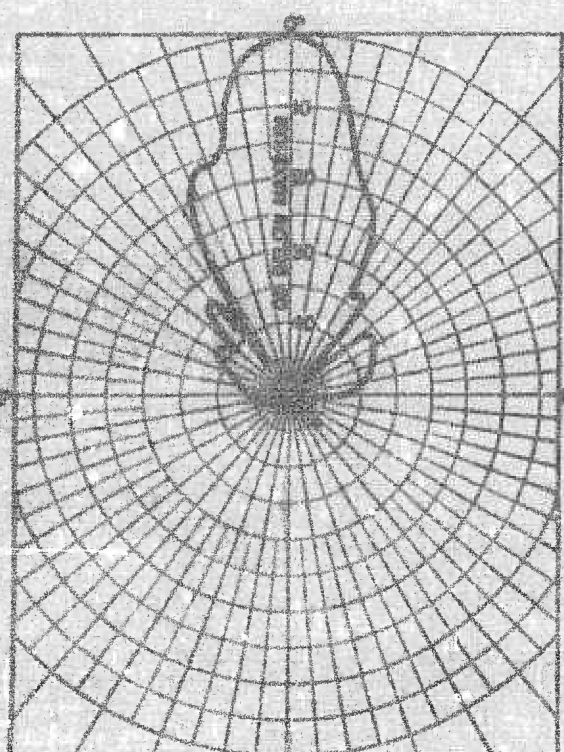


FIGURE 12. Receiving directivity pattern, QCU No. 5 projector at 23.38 kc without dome. Other patterns for this unit and frequency in Figures 13-15.

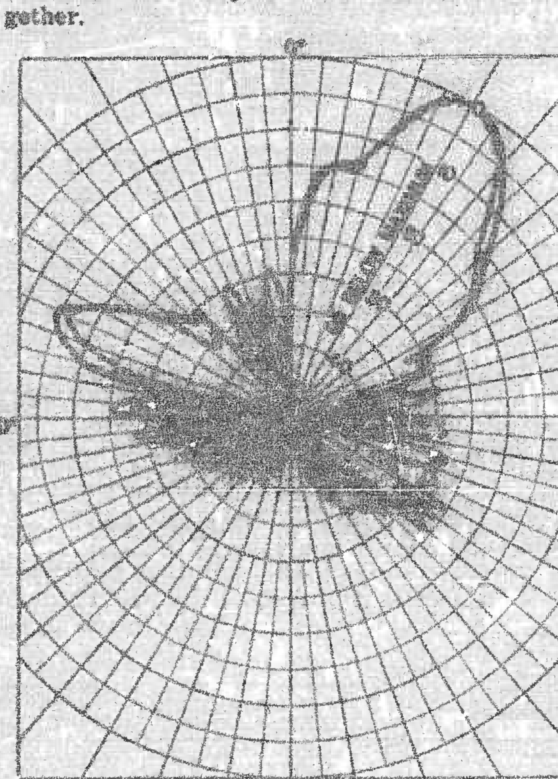


FIGURE 14. Receiving directivity pattern: ——— in QCU-1 dome with baffle, - - - - in QCU-1 dome without baffle. Unit at 30° with respect to dome axis. Projector and dome rotated together.

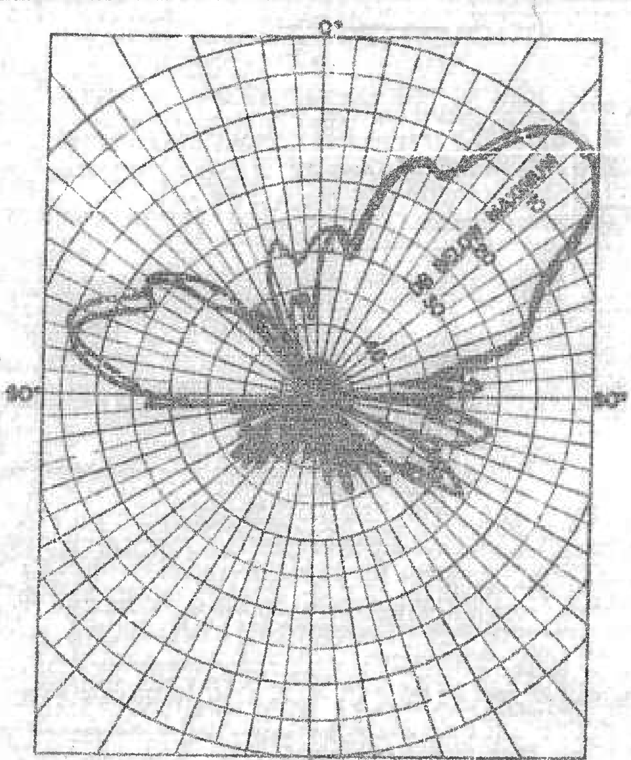


FIGURE 15. Receiving directivity pattern: ——— in QCU-1 dome with baffle, - - - - in QCU-1 dome without baffle. Unit at 45° with respect to dome axis. Projector and dome rotated together.

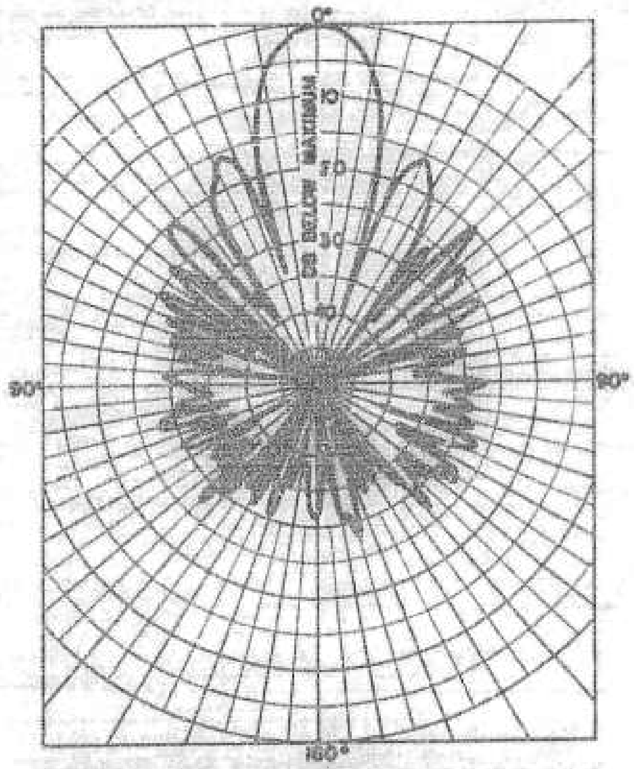


FIGURE 17. Receiving directivity pattern: in 70-in. QCU-2 torpedo dome. Bearing angle 0°. Dome and projector rotated together.

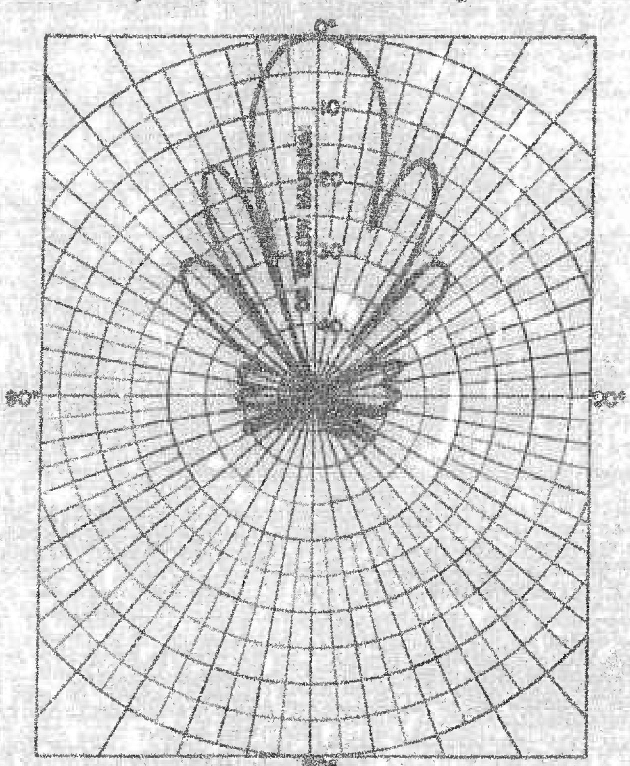


FIGURE 16. Receiving directivity pattern, 14-in. RCA ADP crystal projector at 25 kc. Projector alone. Other patterns for this unit and frequency in Figures 17-19.

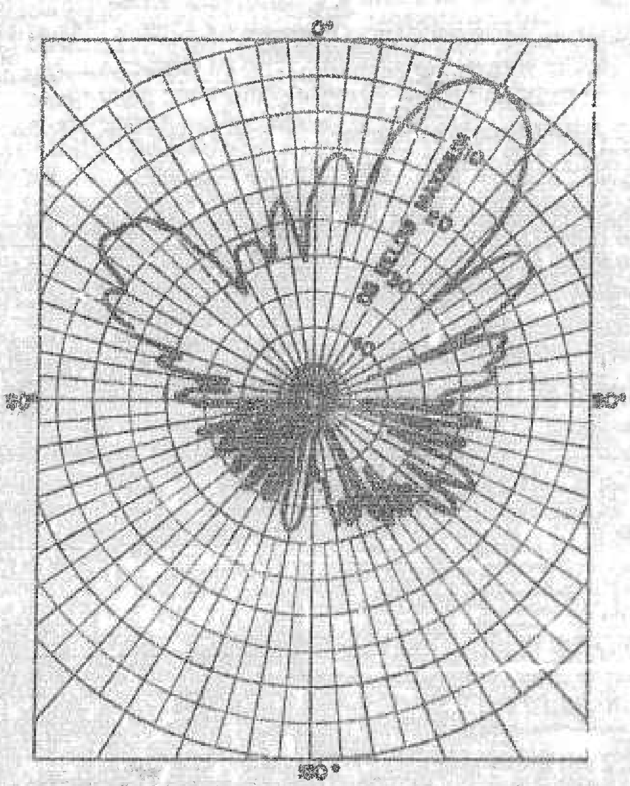


FIGURE 18. Receiving directivity pattern: in 70-in. QCU-2 torpedo dome. Bearing angle 30°. Dome and projector rotated together.

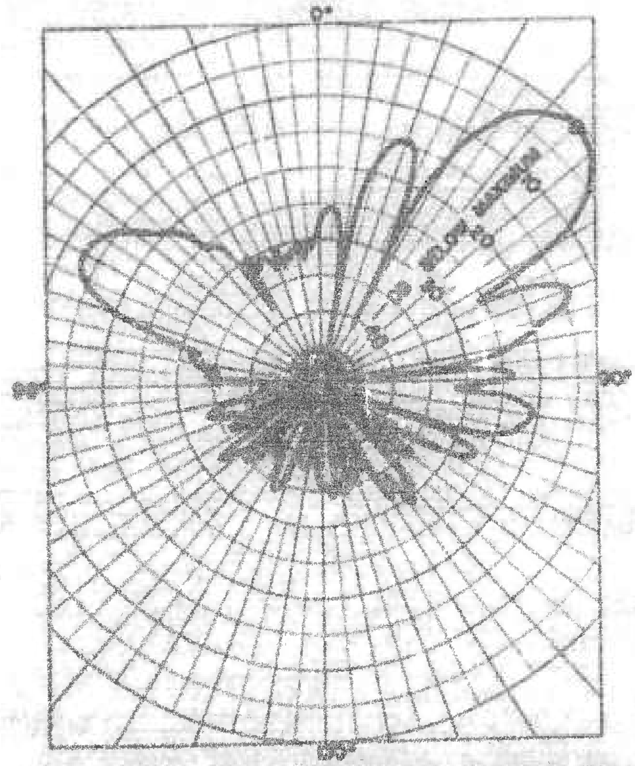


FIGURE 19. Receiving directivity pattern: in 70-in. QCU-2 torpedo dome. Bearing angle 45°. Dome and projector rotated together.

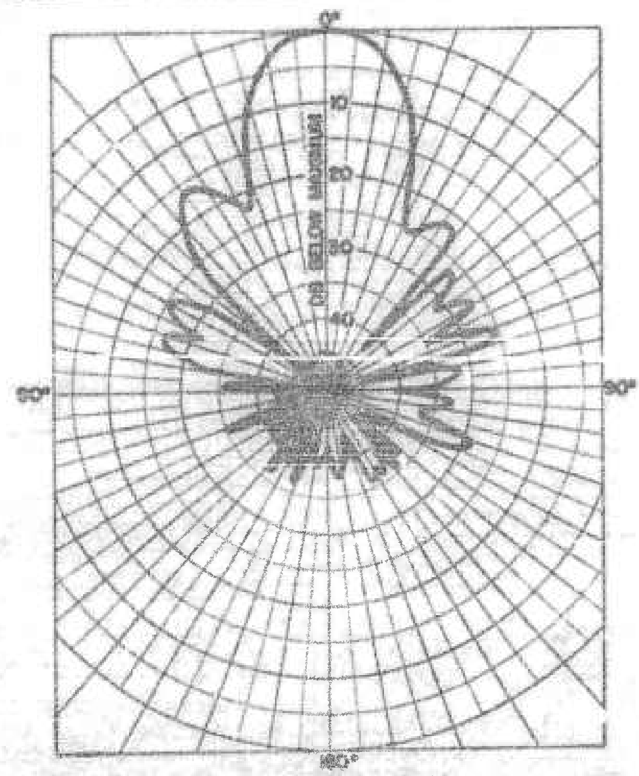


FIGURE 21. Receiving directivity pattern: in 20-mil stainless steel WEA-1 dome. Unit at 0° with respect to dome axis. Projector and dome rotated together.

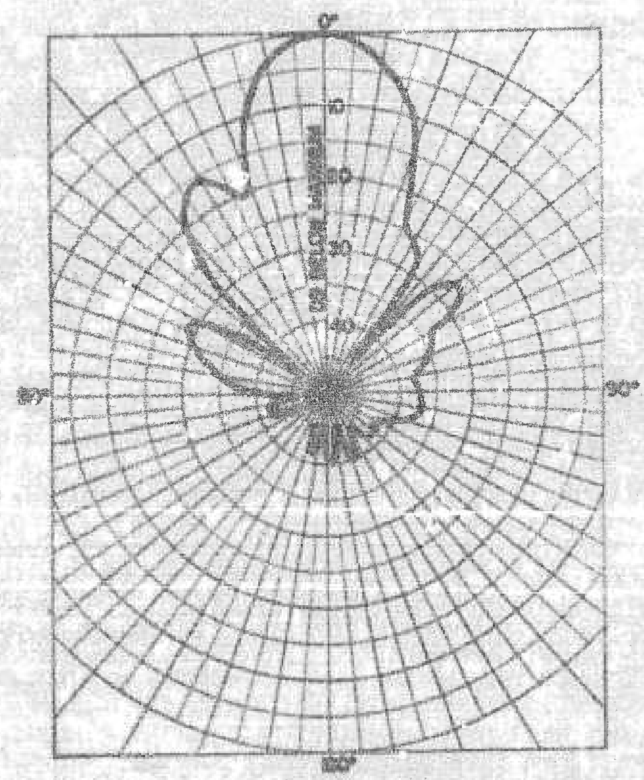


FIGURE 20. Receiving directivity pattern, WEA-1 projector at 24.5 kc without dome. Other patterns for this unit and frequency in Figures 21-29.

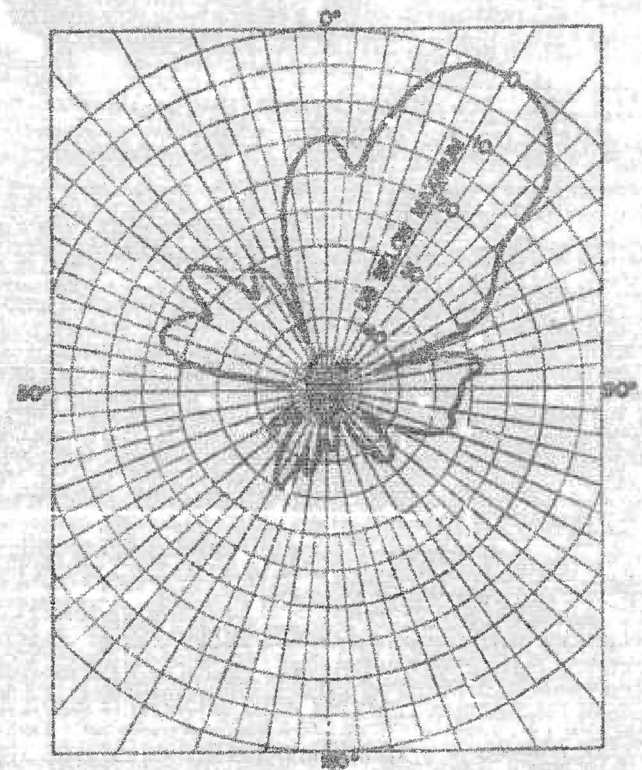


FIGURE 22. Receiving directivity pattern: in 20-mil stainless steel WEA-1 dome. Unit at 30° with respect to dome axis. Projector and dome rotated together.

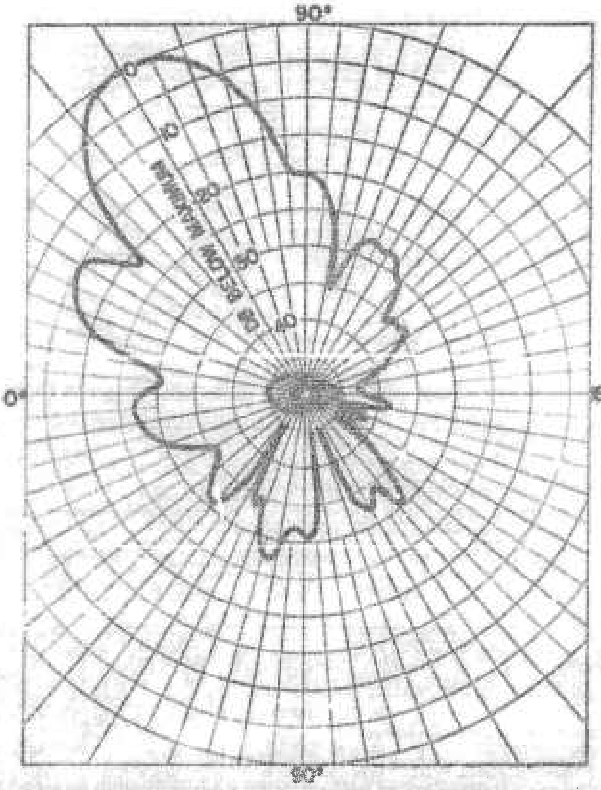


FIGURE 23. Receiving directivity pattern: in 20-mil stainless steel WEA-1 dome. Unit at 60° with respect to dome axis. Projector and dome rotated together.

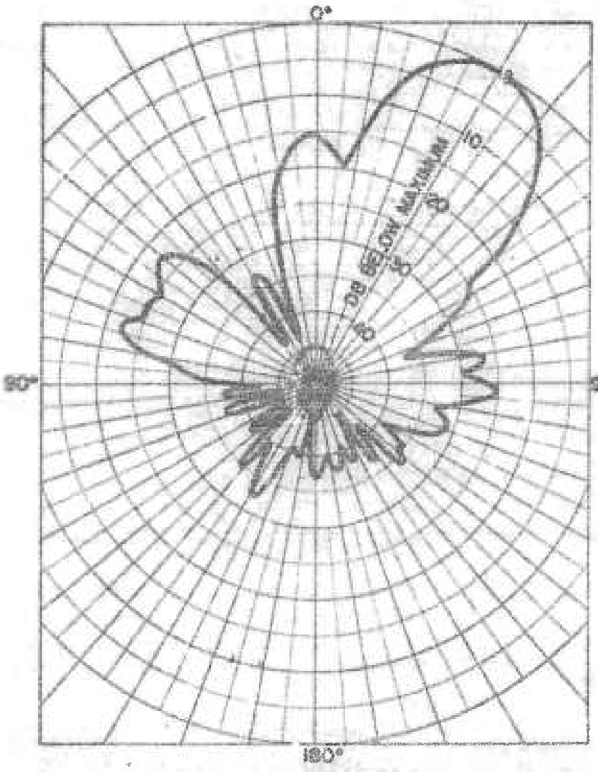


FIGURE 25. Receiving directivity pattern: in 30-mil stainless steel WEA-1 dome. Unit at 30° with respect to dome axis. Projector and dome rotated together.

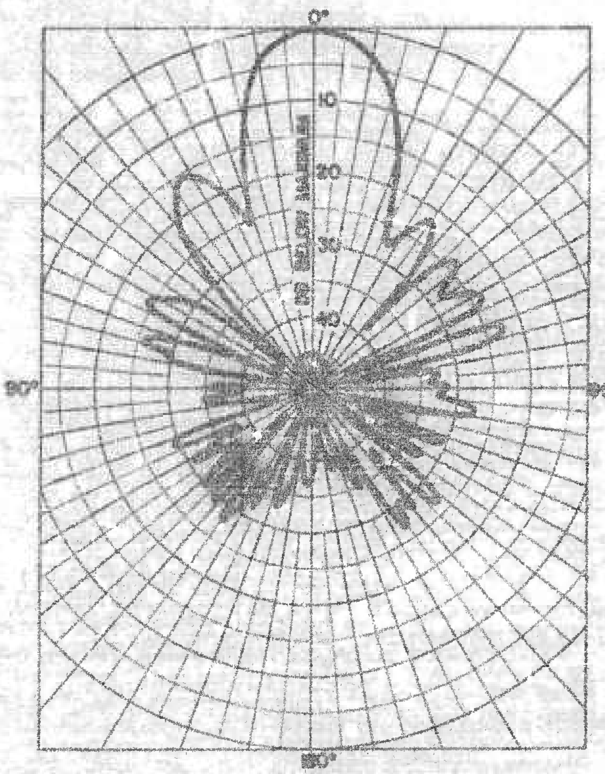


FIGURE 24. Receiving directivity pattern: in 30-mil stainless steel WEA-1 dome. Unit at 0° with respect to dome axis. Projector and dome rotated together.

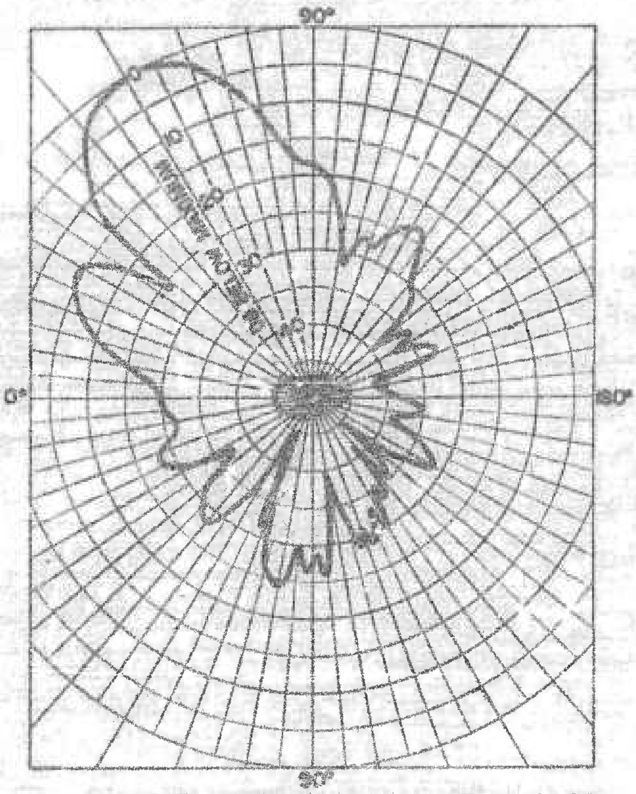


FIGURE 26. Receiving directivity pattern: in 30-mil stainless steel WEA-1 dome. Unit at 60° with respect to dome axis. Projector and dome rotated together.

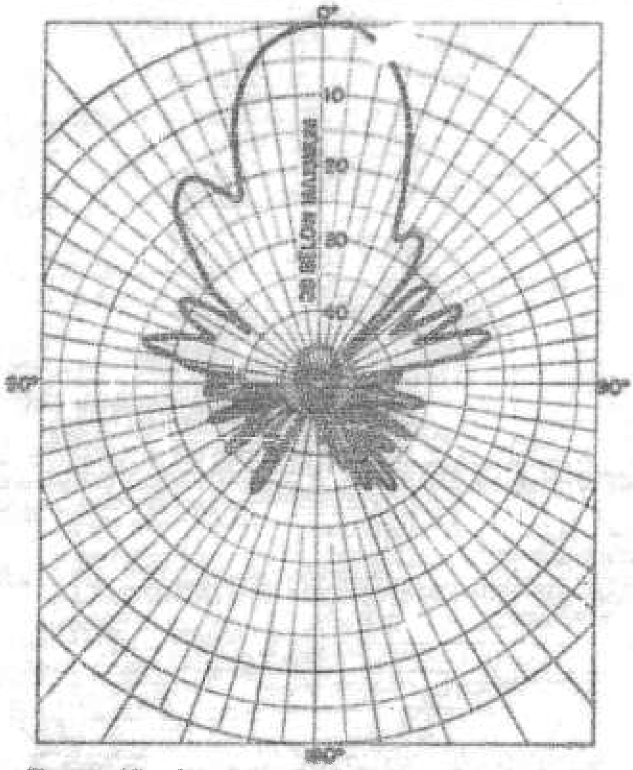


FIGURE 27. Receiving directivity pattern: in 38-mil aluminum WEA-1 dome. Unit at 0° with respect to dome axis. Projector and dome rotated together.

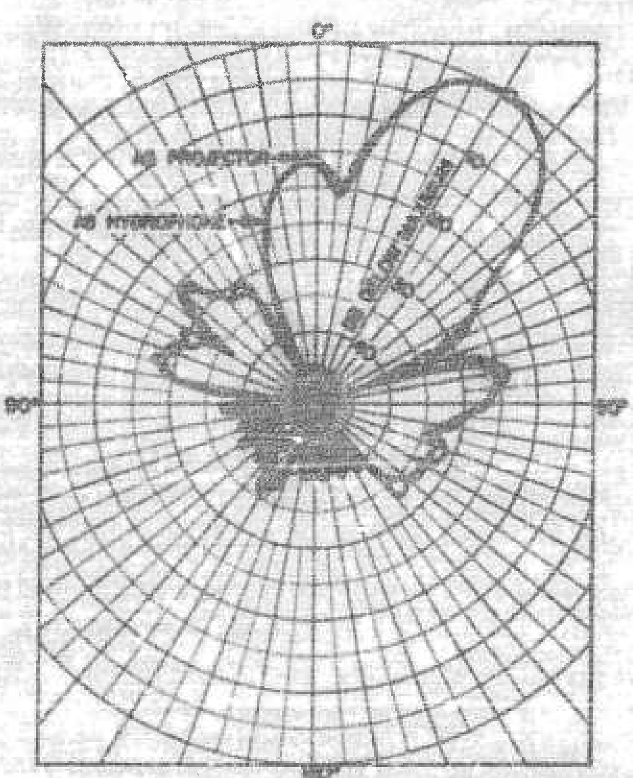


FIGURE 28. Directivity pattern: in 38-mil aluminum WEA-1 dome. Unit at 30° with respect to dome axis. Projector and dome rotated together.

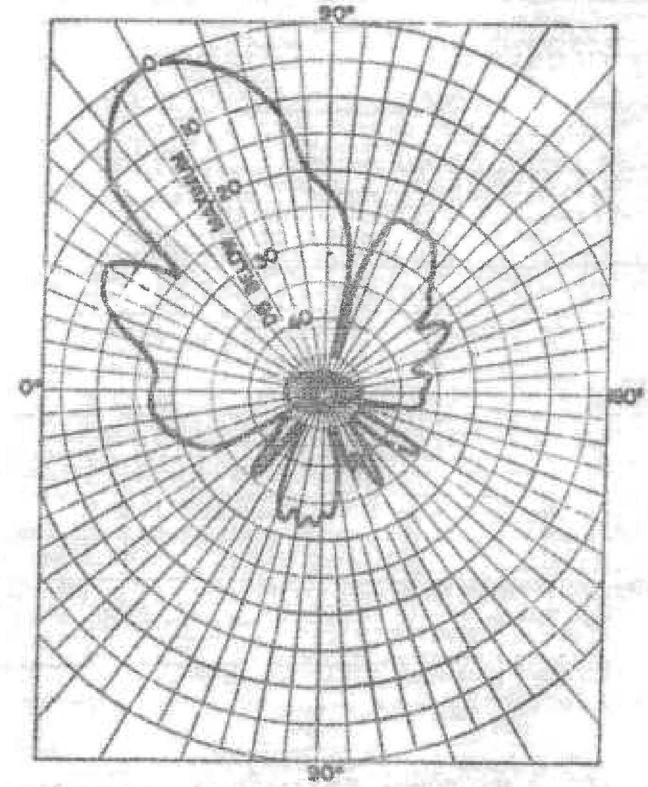


FIGURE 29. Receiving directivity pattern: in 38-mil aluminum WEA-1 dome. Unit at 60° with respect to dome axis. Projector and dome rotated together.

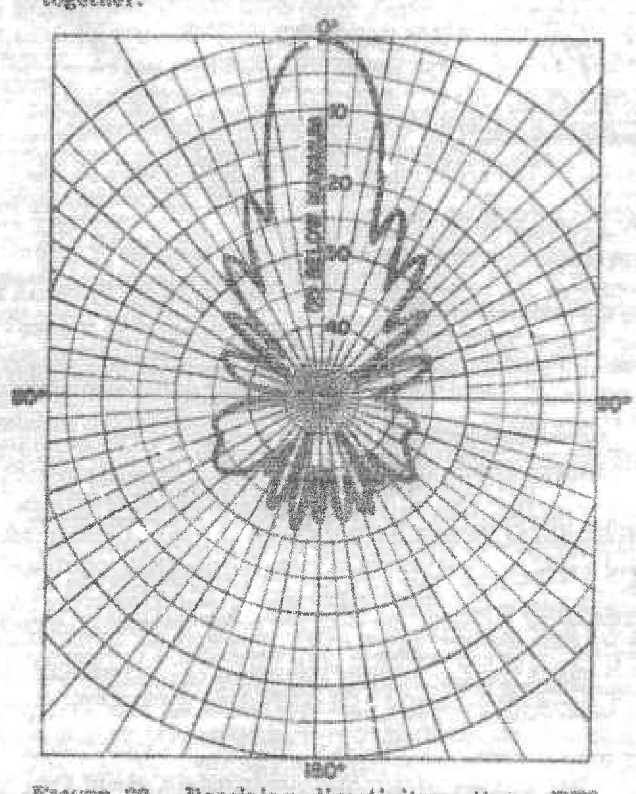


FIGURE 30. Receiving directivity pattern, BTL projector QBF No. 451 at 24 kc without dome. Other patterns for this unit and frequency in Figures 31-33.

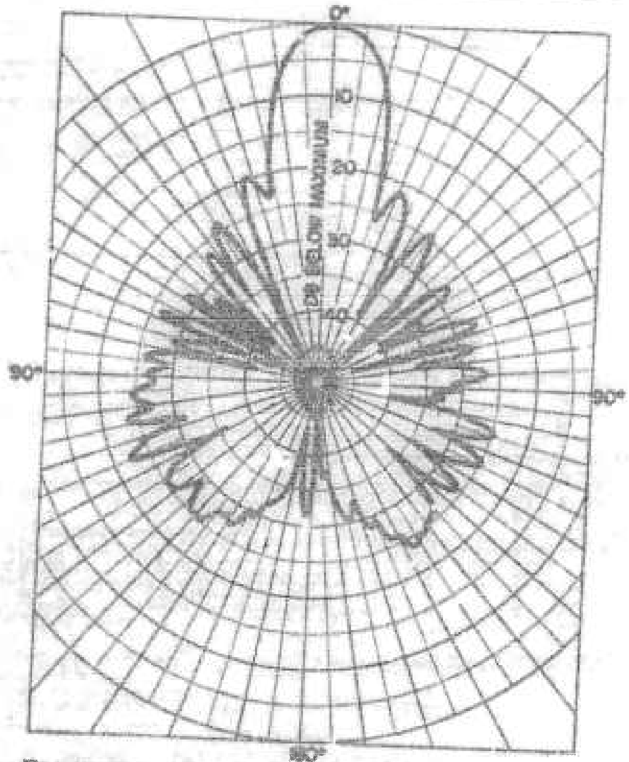


FIGURE 31. Receiving directivity pattern: in QBF dome. Projector at 0° with respect to dome axis. Projector and dome rotated together.

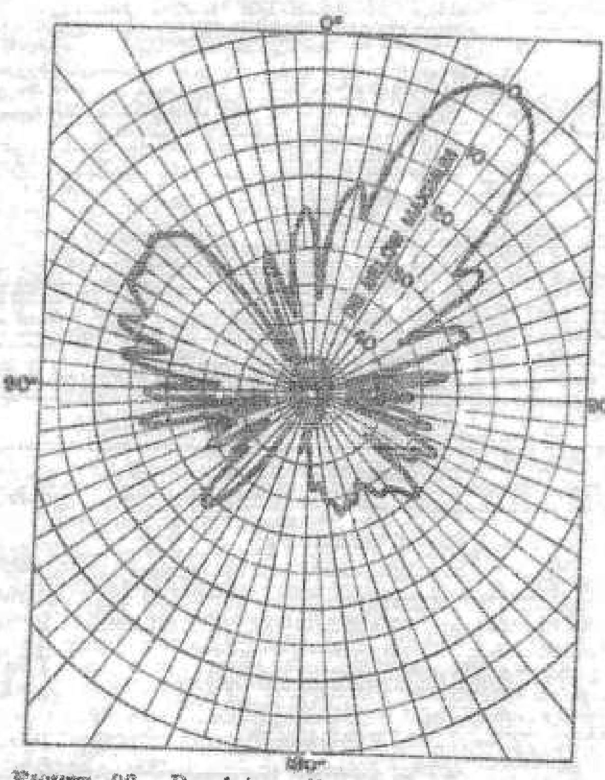


FIGURE 32. Receiving directivity pattern: in QBF dome. Projector at 30° with respect to dome axis. Projector and dome rotated together.

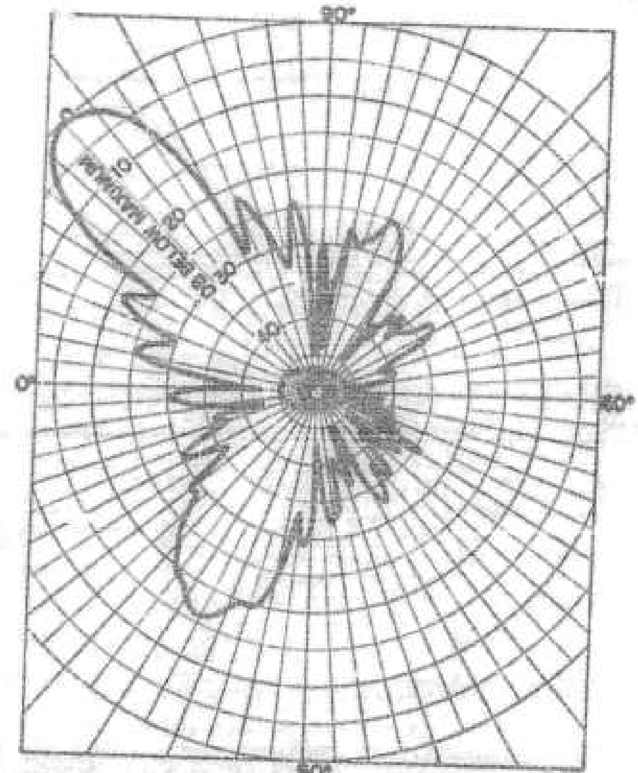


FIGURE 33. Receiving directivity pattern: in QBF dome. Projector at 45° with respect to dome axis. Projector and dome rotated together.

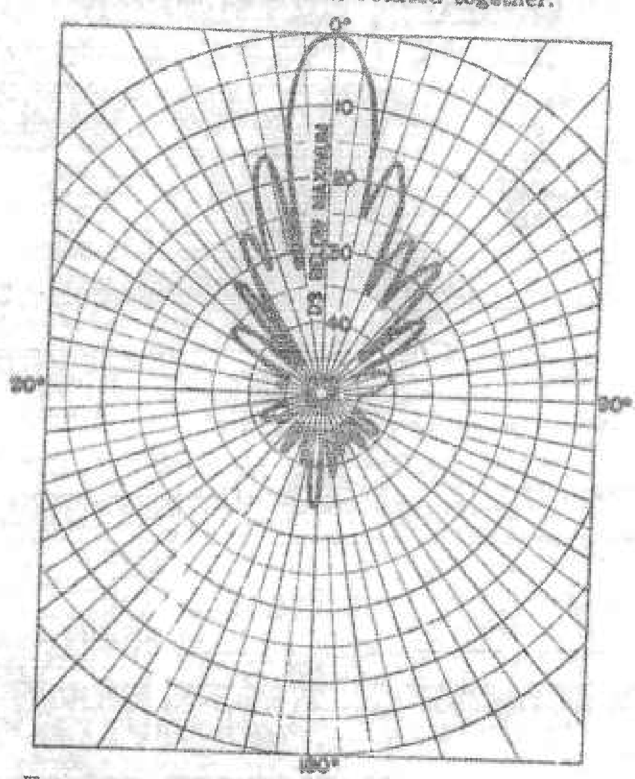


FIGURE 34. Receiving directivity pattern, XQB-6S projector at 25 kc without dome. Other patterns for this unit and frequency in Figures 35-37.

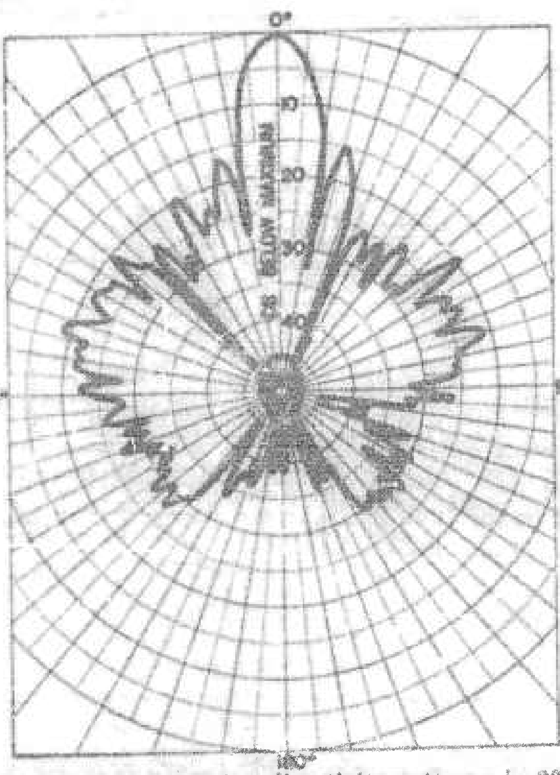


FIGURE 35. Receiving directivity pattern: in 30-mil 54-in. dome No. 892. Projector at 0° with respect to dome axis. Projector and dome rotated together.

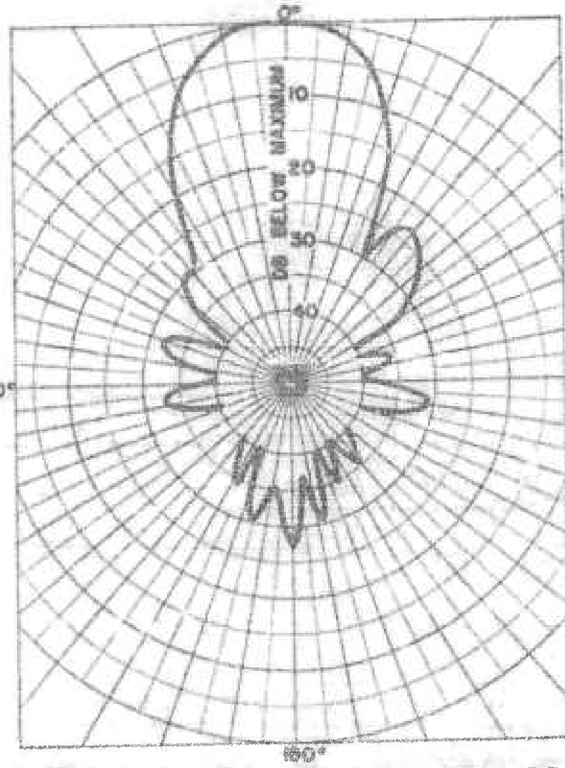


FIGURE 37. Receiving directivity pattern, QGA transducer 94111A at 14.72 kc without dome. Other patterns for this unit and frequency in Figures 38-40.

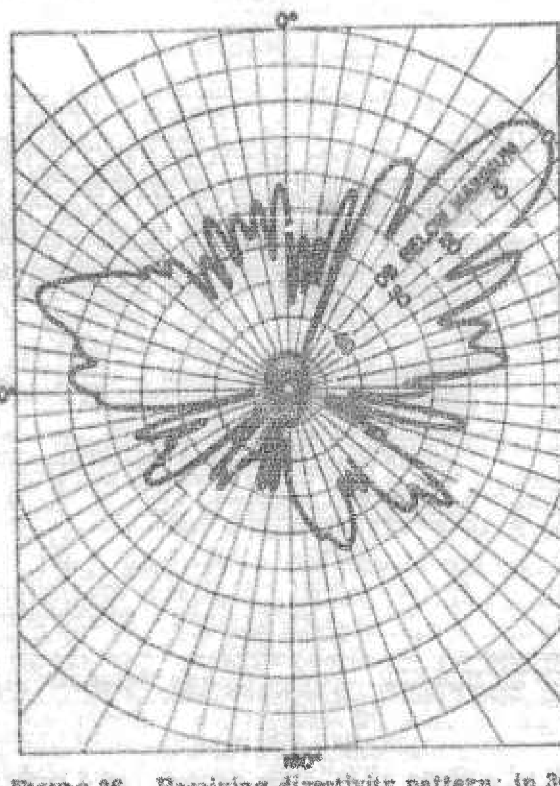


FIGURE 36. Receiving directivity pattern: in 30-mil 54-in. dome No. 892. Projector at 45° with respect to dome axis. Projector and dome rotated together.

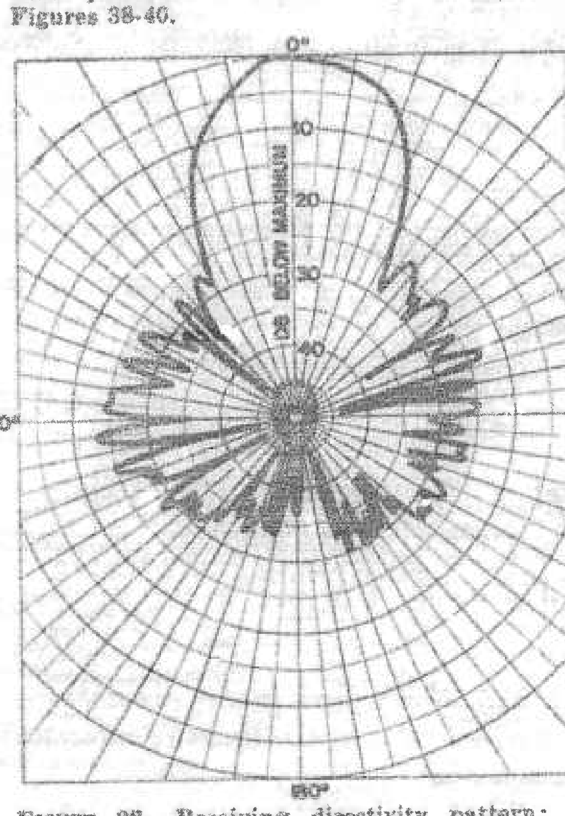


FIGURE 38. Receiving directivity pattern: in 100-in. QGA dome. Transducer at 30° with respect to dome axis. Transducer and dome rotated together.

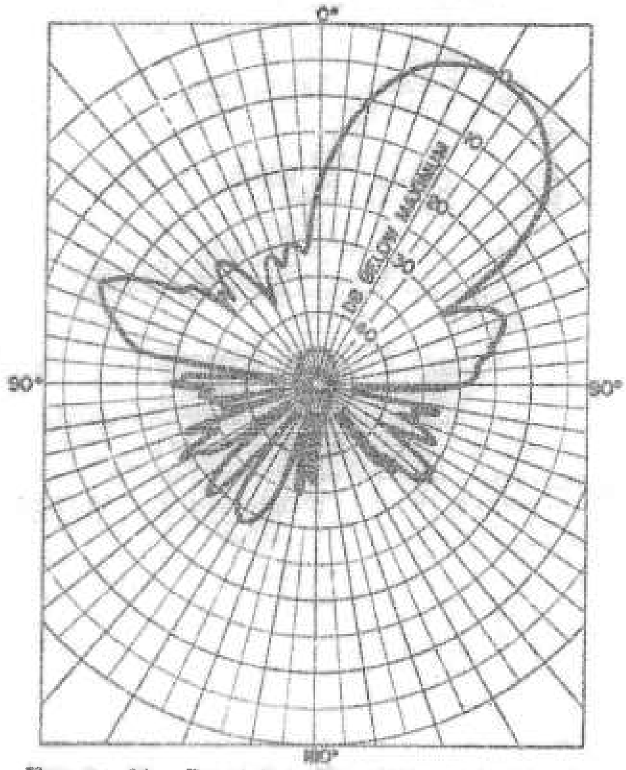


FIGURE 39. Receiving directivity pattern: in 100-in. QGA dome. Transducer at 30° with respect to dome axis. Transducer and dome rotated together.

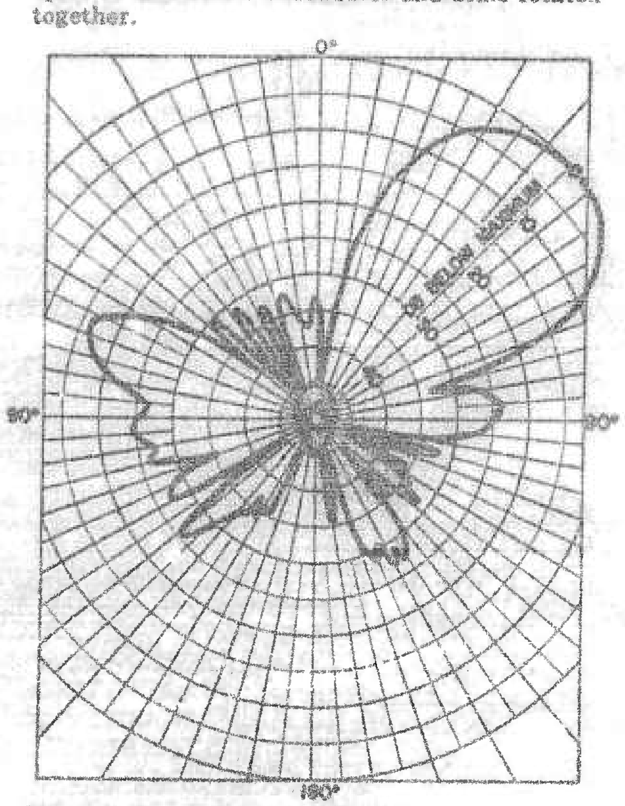


FIGURE 40. Receiving directivity pattern: in 100-in. QGA dome. Transducer at 45° with respect to dome axis. Transducer and dome rotated together.

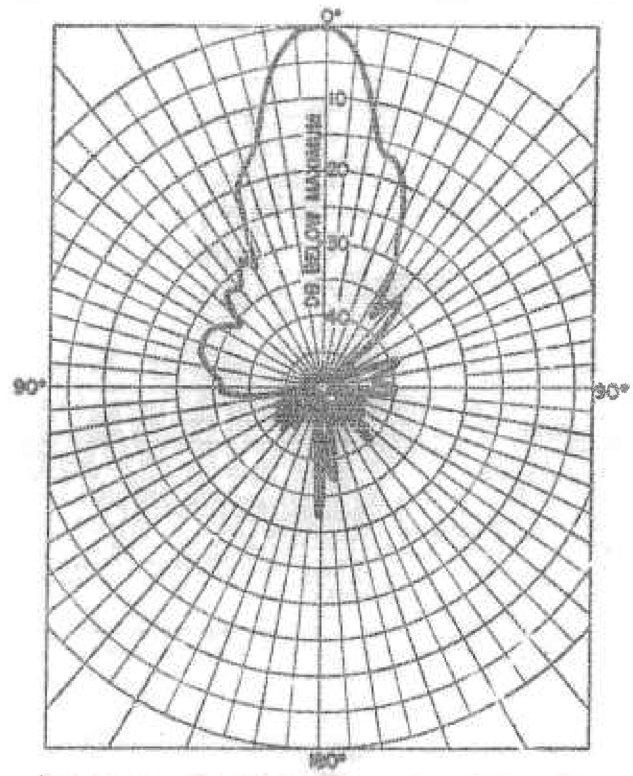


FIGURE 41. Receiving directivity pattern, QGA transducer 94211A at 30.47 kc without dome. Other patterns for this unit and frequency in Figures 42-44.

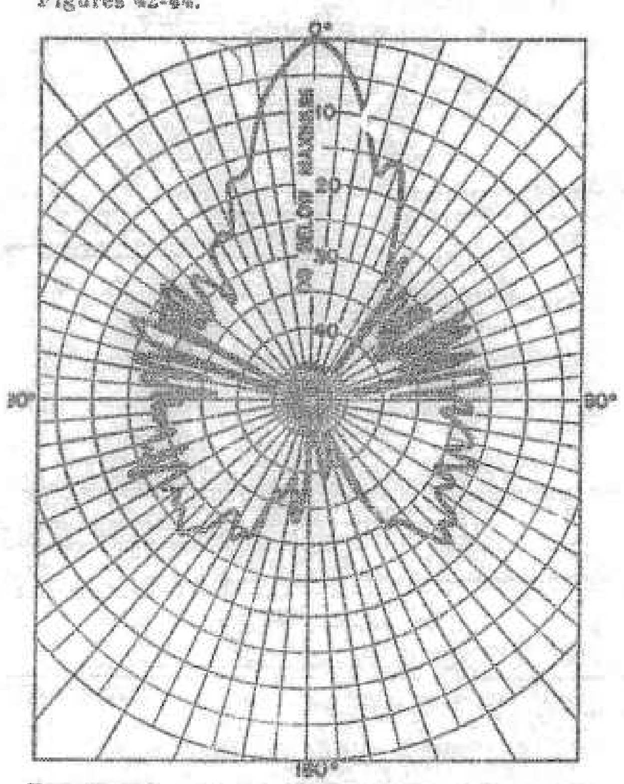


FIGURE 42. Receiving directivity pattern: in 100-in. QGA dome. Transducer at 0° with respect to dome axis. Transducer and dome rotated together.

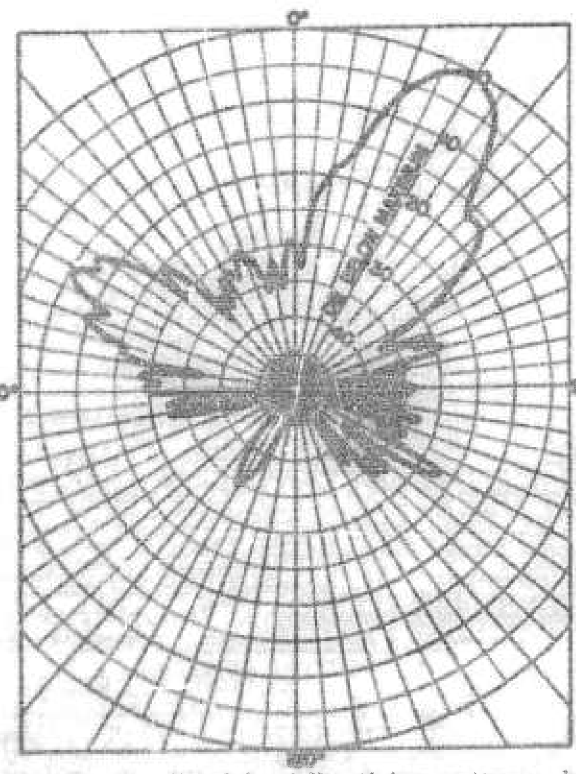


FIGURE 43. Receiving directivity pattern: in 100-in. QGA dome. Transducer at 30° with respect to dome axis. Transducer and dome rotated together.

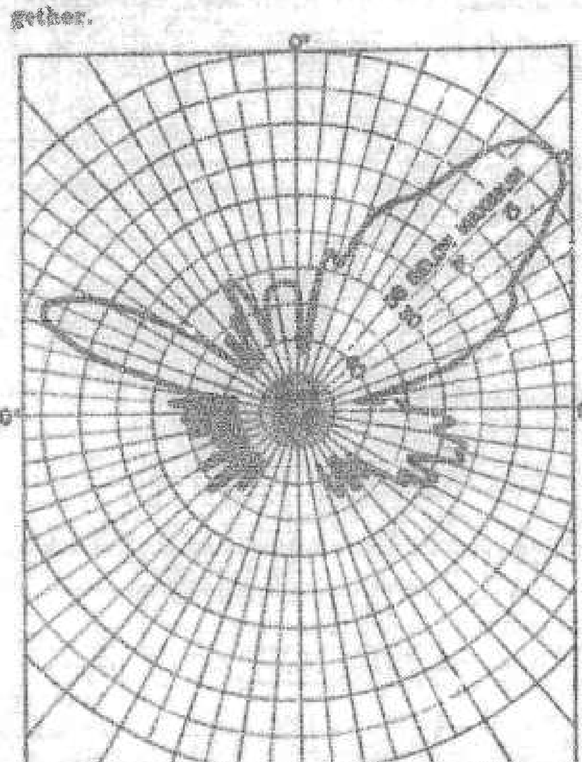


FIGURE 44. Receiving directivity pattern: in 100-in. QGA dome. Transducer at 45° with respect to dome axis. Transducer and dome rotated together.

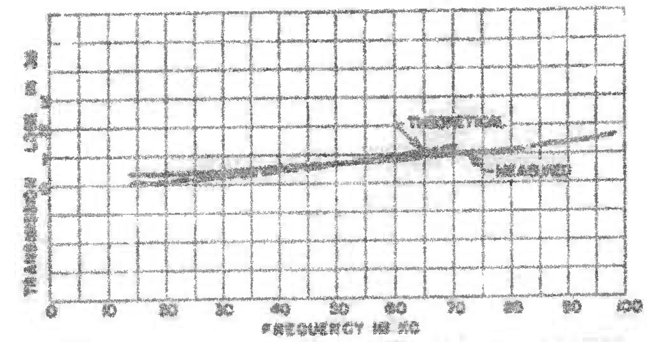


FIGURE 45. Transmission loss of 100-in. QGA dome versus frequency.

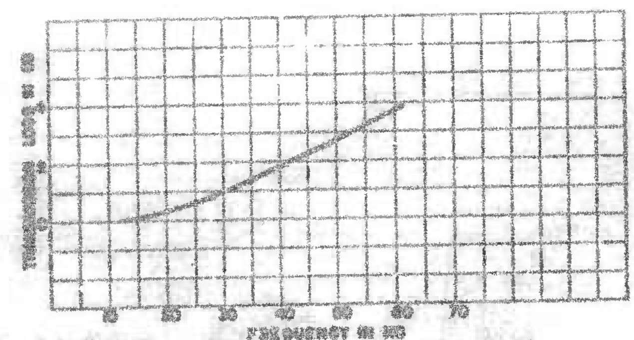


FIGURE 46. Transmission loss of QBF dome versus frequency.

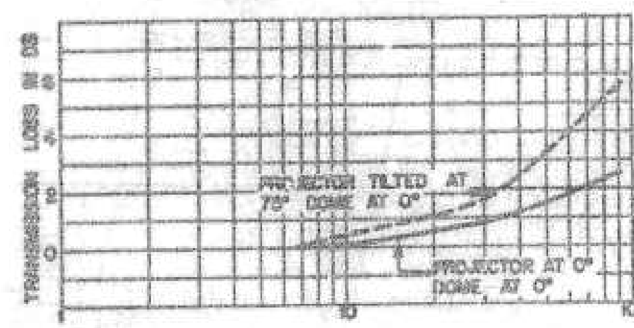


FIGURE 47. Transmission loss of QCU-2 torpedo dome versus frequency.

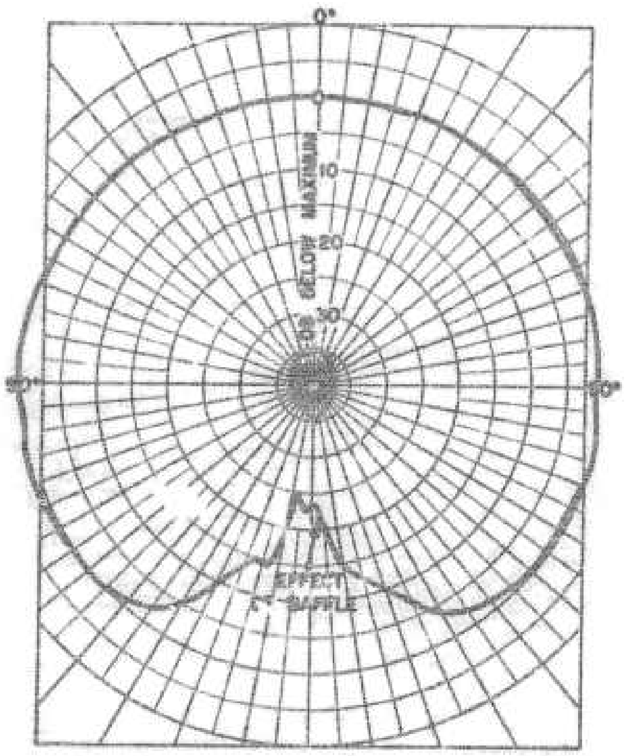


FIGURE 48. Measured attenuation of QBF projector response due to QBF dome. Used as a hydrophone at 24 kc. Dome rotated. Unit fixed at 0° with reference to sound source.

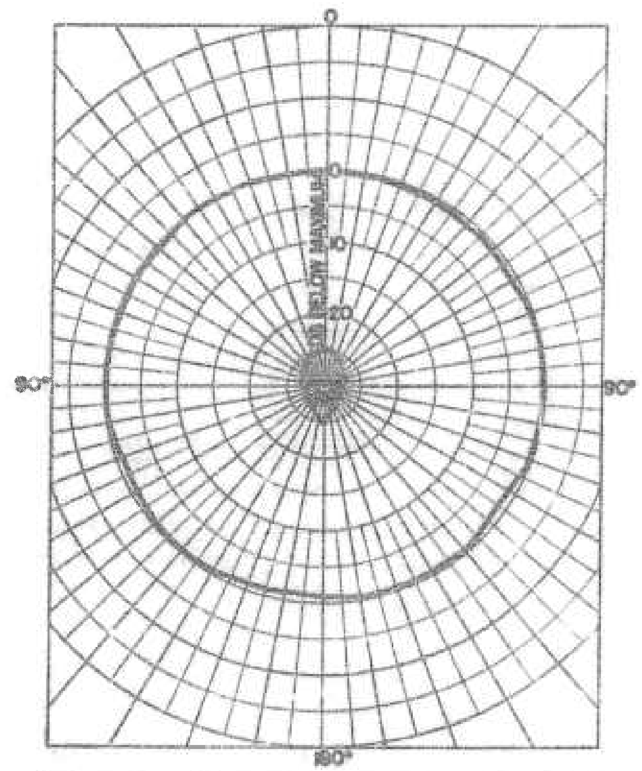


FIGURE 49. Measured attenuation of WEA-1 projector response due to 38-mil aluminum dome. Used as a hydrophone at 24.5 kc. Dome rotated. Unit fixed at 0° with reference to sound source.

Chapter 4

BRITISH AND CANADIAN EQUIPMENT

4.1 ASDIC AND HYDROPHONE UNITS

THE EQUIPMENT DESCRIBED in this chapter includes four Asdic units and five hydrophones. Asdic[66] is the term used to designate any British or Canadian sonar equipment having both listening and echo-ranging features, although some gear used for listening only have been called Asdic. The Asdics described herein are both echo-ranging and listening devices. They have been designed for practically every class of ship, and various frequencies are used so that ships operating in a group do not suffer from mutual interference.

The original Asdic oscillator consisted of a quartz steel sandwich tuned by the thickness of the steel plates, as in the Asdic Oscillator A/S 96. Now Rochelle salt crystals and ADP crystals are also used, as well as magnetostrictive coupling, e.g., Asdic Set, Type 185 and Asdic Transducer, Type 150. Tourmaline is used in special hydrophones, e.g., HT-1, and quartz is used in others, e.g., Type P, Quartz Crystal Low-Frequency Standard. Forty-five degree X-cut Rochelle salt crystals are used in the Canadian B1 and F1 hydrophones.

4.1.1

Asdic Oscillator A/S 96

Type: Quartz Crystals between Steel Plates.

Reference: NDRC Report No. 6.1-sr20-608, March 4, 1943.[105]

Use: Echo ranging.

Description: The Asdic Oscillator A/S 96 (equivalent to A/S 95), Pattern No. 1200, consists of disk quartz between steel face plates. The resonance of the oscillator is determined by the thickness of the steel face plates in conjunction with the stiffness of the quartz disks. The oscillator frequency is designated by the suffix letter in the serial number, Y indicating 14 kc; A, 15 kc; B, 16 kc; C, 17 kc, etc. The unit illustrated resonated at about 15 kc.

For transmitting, the oscillator is supplied from a circuit having a resistance of 52 ohms and an inductance of about 17 mh. For reception the oscillator is connected across a high Q coil having an inductance of 18 mh. A trimmer condenser connected across the oscillator terminals is used for fine adjustment of the frequency of resonance of the unit.

Efficiency at resonance: —3 db vs ideal.

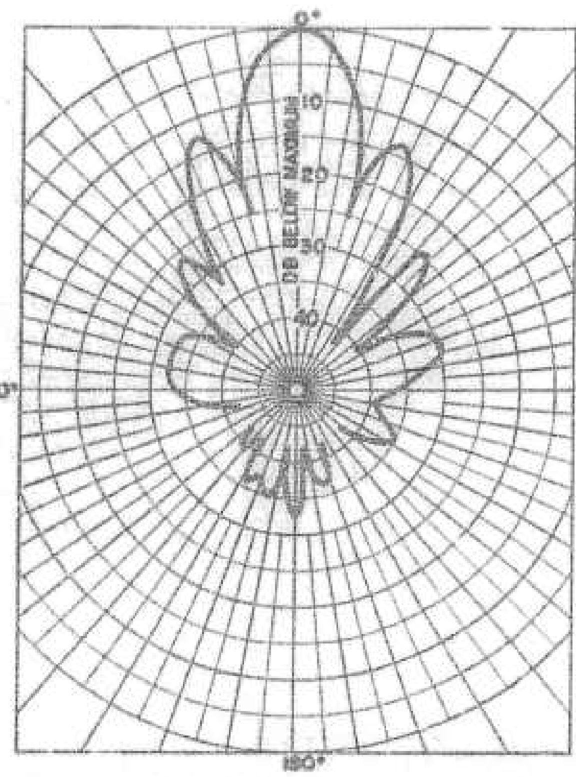


FIGURE 1. Directivity pattern, Asdic oscillator A/S 96 at 14.94 kc. Directivity index = —22.0 db.

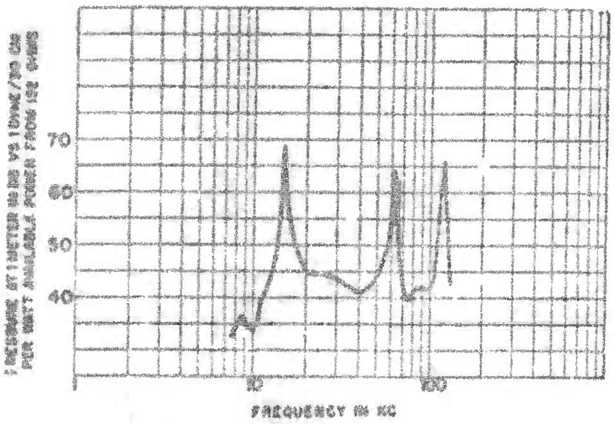


FIGURE 2. Transmitting response, Asdic oscillator A/S 96. Water temperature = 64 F.

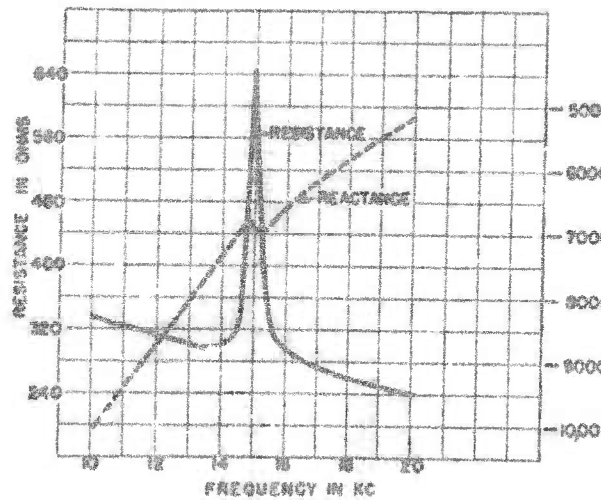
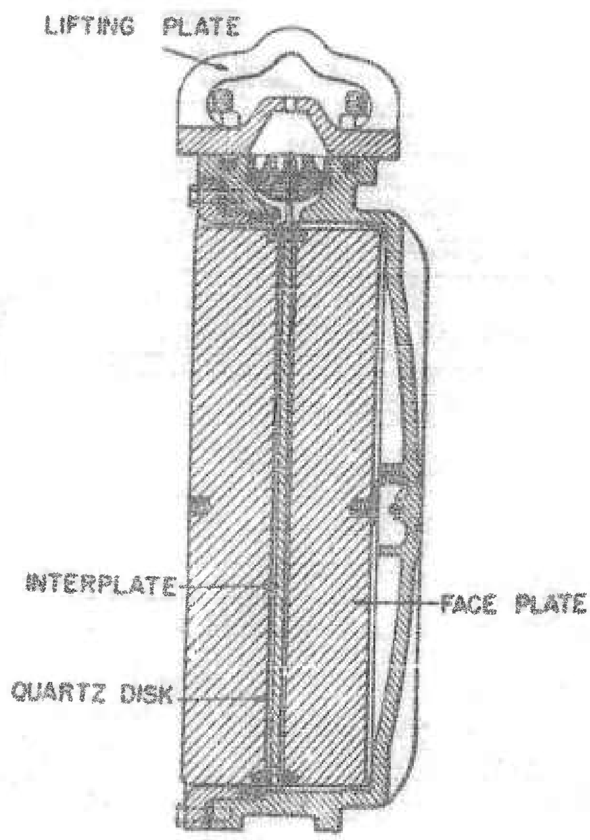


FIGURE 4. Impedance, Asdic oscillator A/S 96.



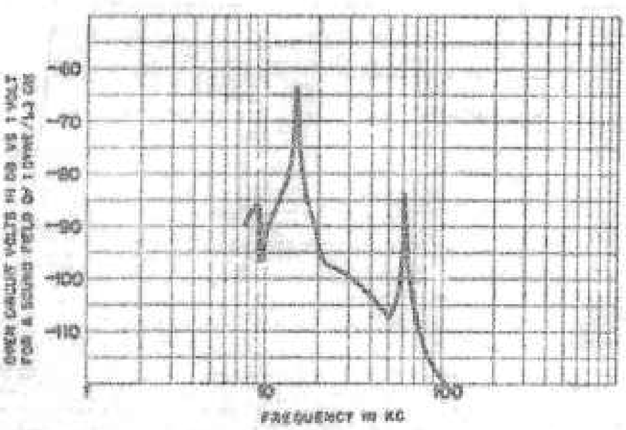


FIGURE 3. Receiving response, Asdic oscillator A/S 96. Water temperature = 64 F. Q = 40. Calculated threshold at 14.94 kc = —103 db vs 1 dyne per sq cm.

FIGURE 5. Asdic oscillator A/S 96.

Type: Magnetostriction.

Reference: NDRC Report No. 6.1-sr1130-1827, September 4, 1944.[109]

Use: Locating small objects.

Description: The Asdic Set, Type 135 uses two identical magnetostriction transducers, one for transmitting pulses of damped sinusoidal oscillations produced by a condenser discharge, the other for receiving incoming acoustic echoes. The active element of the transducer consists of a stack of annular nickel laminations 5 in. in diameter by 2⅝ in. high. Around this stack is a toroidal winding of 24 turns of insulated wire. A surge of current through this winding will cause the stack to contract. Restoring forces will then cause the stack to oscillate at the resonant frequency, about 15 kc. To obtain a directional response each unit is mounted in a double-walled, air-filled, parabolic reflector. The transmitting unit is normally polarized by the d-c component of the condenser-discharge input. The receiving unit is polarized by the residual magnetism from a large current flowing through the winding for a very short time.

Other essential units in the Asdic Set, Type 135 are a recorder unit, a contractor unit, and an amplifier-rectifier unit. The recorder unit consists of a chemical recorder, a cam operating a transmitter switch, and a second cam operating the time-varied gain [TVG] feature in the receiving amplifier. The function of the transmitter switch is to energize the contactor which charges a 4-μf condenser and discharges it through the transmitting unit. Incoming acoustic signals are converted to electric energy in the receiving unit and passed through the amplifier-rectifier unit to the chemical recorder through the pen stylus which sweeps across the paper from left to right. The TVG of the amplifier-rectifier unit is obtained by changing the grid bias exponentially by means of a condenser discharge. The instant at which the condenser begins discharging is controlled by the switch in the recorder unit.

A "subtraction circuit," not shown in the schematic, is used to smooth out the reverberation background and thus allow the recorder trace to stand out more sharply on the record. This subtraction circuit is basically a network for insertion between the output of the amplifier-rectifier and the recorder to remove the d-c components from the signal.

Efficiency: receiving unit: —14.5 db vs ideal.
transmitting unit: —14.3 db vs ideal.

Peak sound pressure in generated acoustic pulse: 1.16×10^6 dynes per sq cm.

Amplification of tuned circuit and amplifier: approximately 100 db at 15 kc.

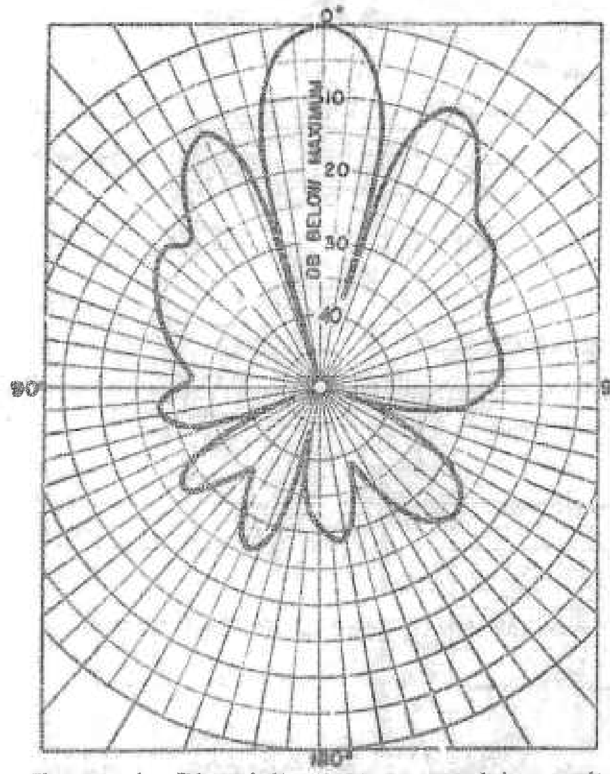


FIGURE 6. Directivity pattern, receiving unit Asdic set, Type 135, at 15.4 kc. Directivity index = —18.9 db.

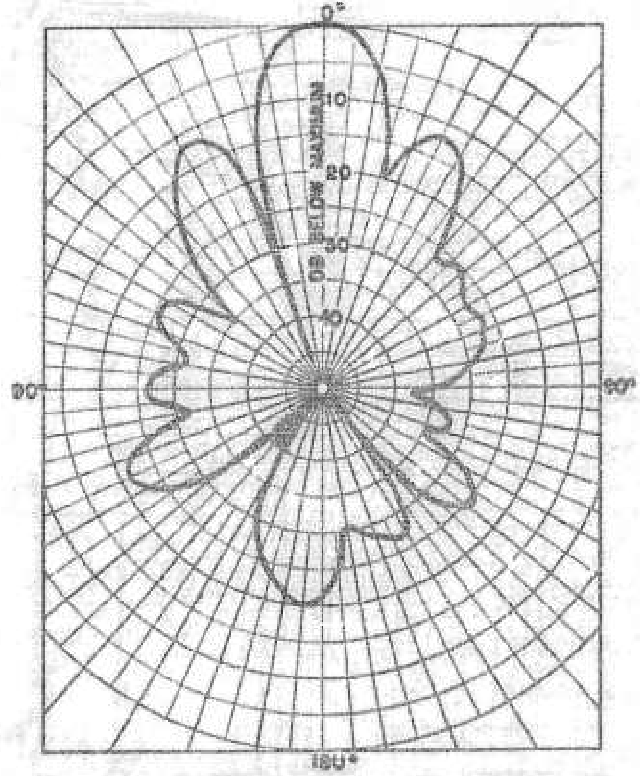


FIGURE 7. Directivity pattern, transmitting unit Asdic set, Type 135, at 14.9 kc. Directivity index = —19.6 db.

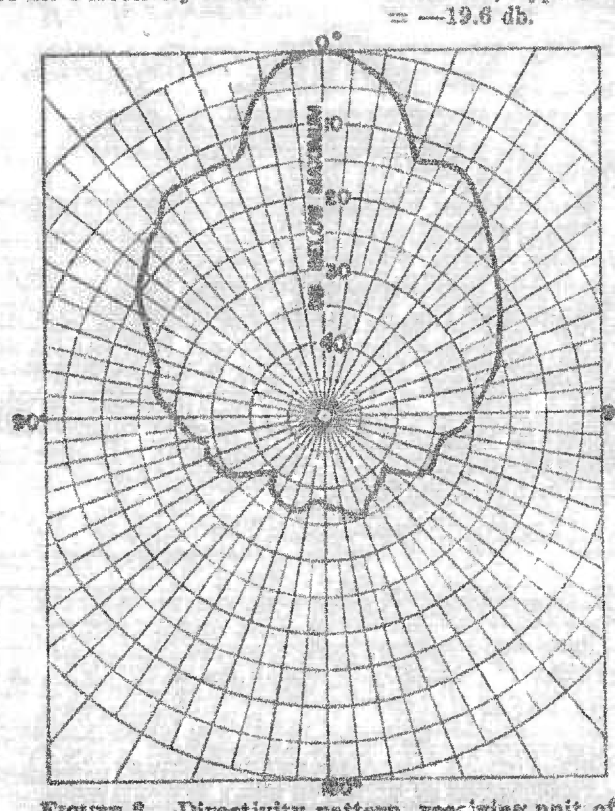


FIGURE 8. Directivity pattern, receiving unit of Asdic set, Type 135, for peak pressure of condenser-discharge pulse. Transmitted by A/S 135 transmitting unit.

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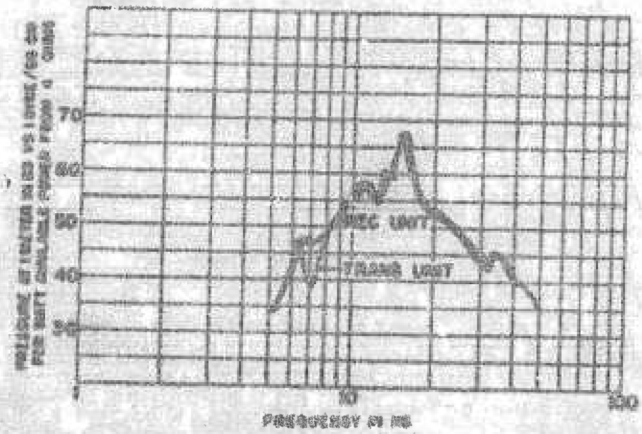

FIGURE 9. Transmitting response, Asdic set, Type 135. Q = 12.

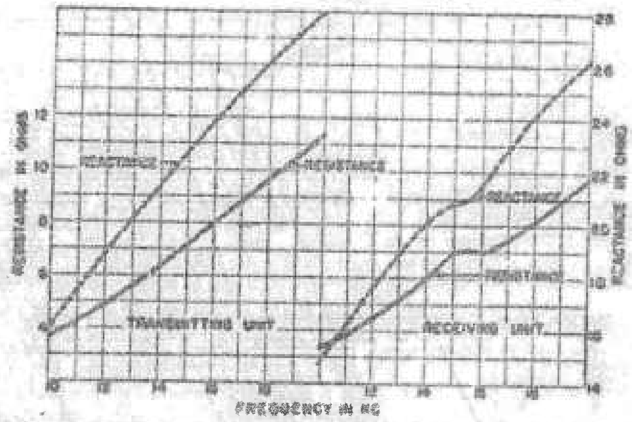

FIGURE 11. Impedance, Asdic set, Type 135.

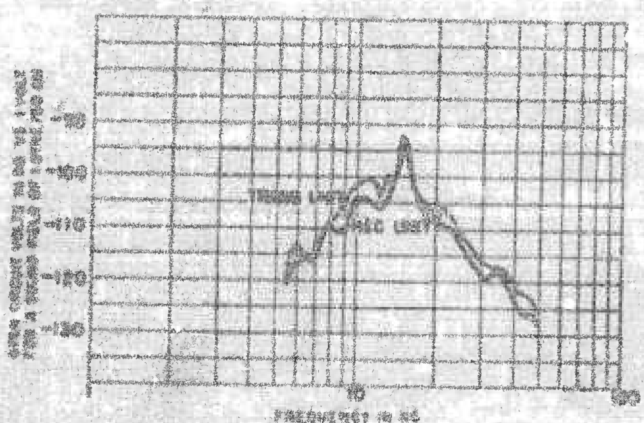

FIGURE 10. Receiving response, Asdic set, Type 135. Q = 12. Calculated threshold: receiving unit at 15.4 = −95 db vs 1 dyne per sq cm; transmitting unit at 14.9 kc = −95 db vs 1 dyne per sq cm.

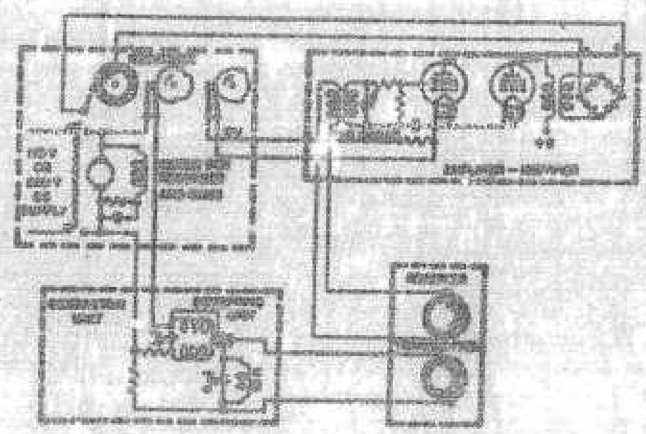

FIGURE 12. Simplified circuit schematic, Asdic set, Type 135.

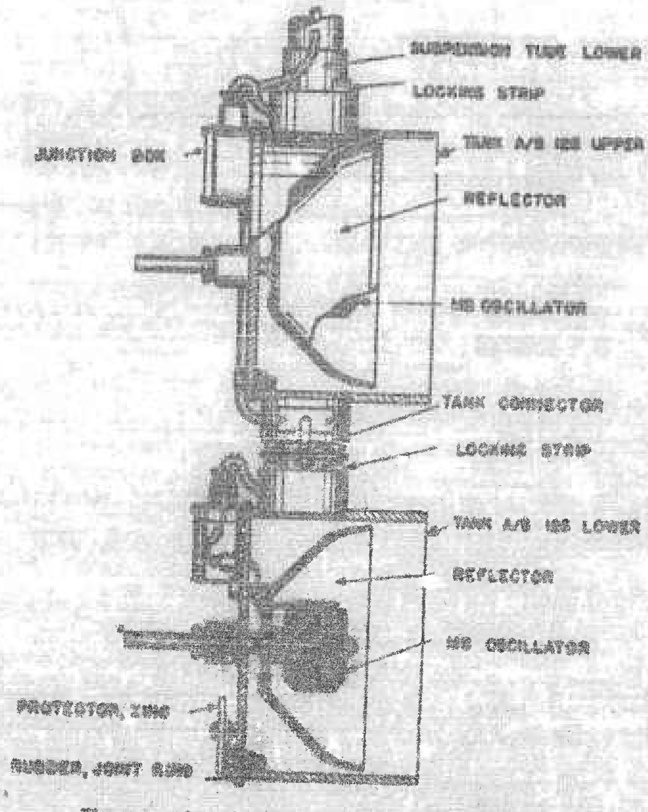

FIGURE 13. Asdic set, Type 135 oscillator.

6.1.3 Asdic Transducer, Type 150

Type: Magnetostriction.
Reference: NDRC Report No. 6.1-sr1130-2136, February 17, 1945.[110]
Use: Locating small objects.
Description: The Asdic Transducer, Type 150 is a magnetostrictive type similar in many respects to the Type 135 transducer. The active element consists of a stack of annular nickel laminations on which is a toroidal winding of insulated wire. Each stack is about 1½ in. high and 5 in. in diameter. Two of the units are mounted one behind the other in a single parabolic reflector enclosed in a spherical shell approximately 12 in. in diameter. The shell is filled with water. One magnetostrictive element serves as the shock-excited transmitter while the other is used as the receiver. The electric circuit used with the Type 150 transducer is essentially the same as is used in the Asdic Set, Type 135. The transmitting unit is normally polarized by the d-c component of the condenser-discharge input. The receiving unit is polarized by the residual magnetization produced by a large current which flows through the winding for a very short time.
Efficiency: receiving unit: —15 db vs ideal.
transmitting unit: —19 db vs ideal.

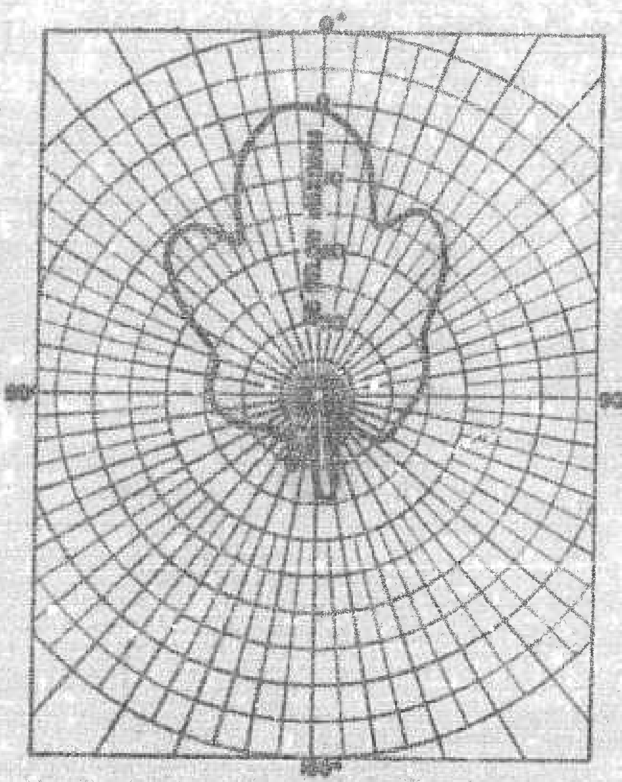

FIGURE 14. Directivity pattern, receiving unit Asdic transducer, Type 150, at 12.8 kc. Directivity index = —19.5 db.

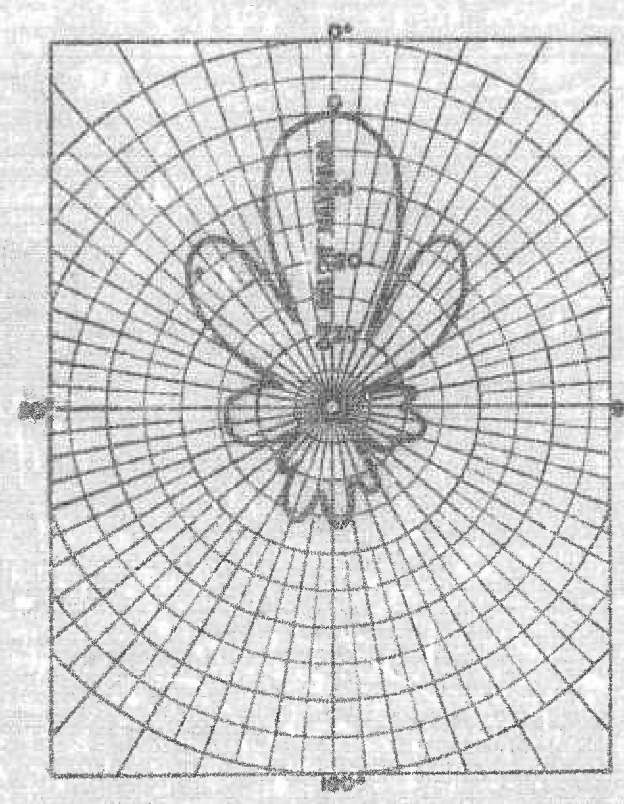

FIGURE 15. Directivity pattern, transmitting unit Asdic transducer, Type 150, at 14.1 kc. Directivity index = —19.5 db.

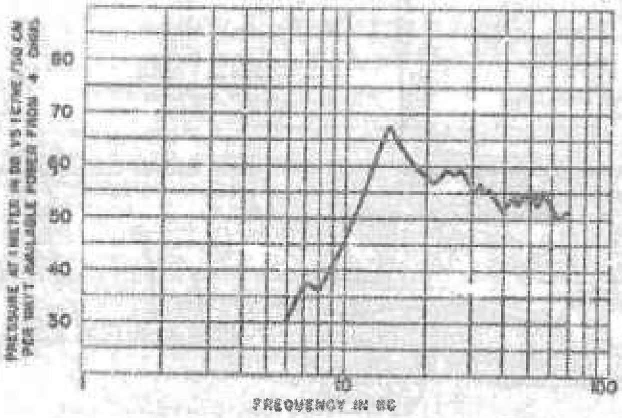

FIGURE 16. Transmitting response, Asdic transducer, Type 150. Water temperature = 60 F.

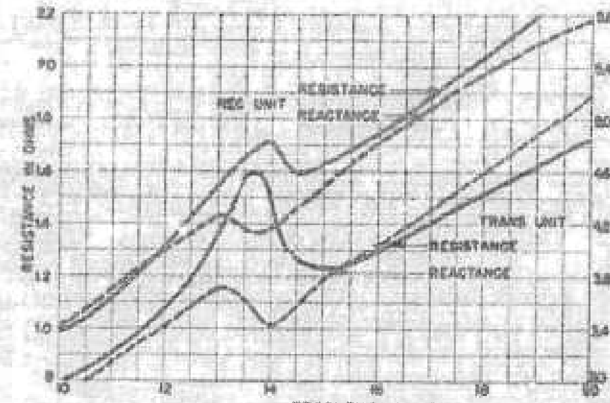

FIGURE 18. Impedance, Asdic transducer, Type 150.

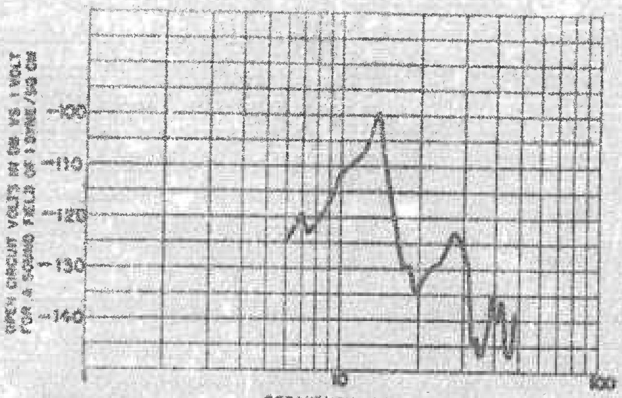

FIGURE 17. Receiving response, receiving unit Asdic transducer, Type 150. Water temperature = 60 F. Calculated threshold at 18.8 kc = —93 db vs 1 dyne per sq cm.

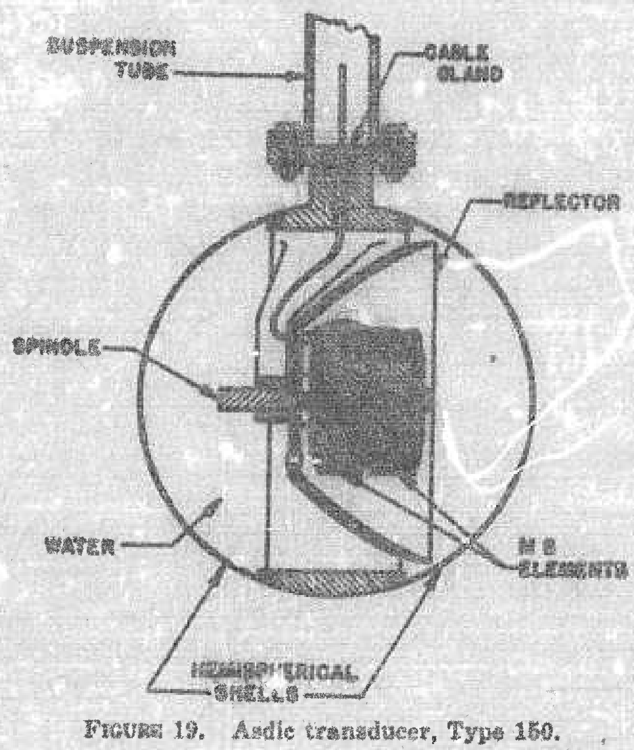

FIGURE 19. Asdic transducer, Type 150.

4.1.4 HT-1 Hydrophone

Type: Tourmaline Crystal.

Reference: NDRC Report No. 6.1-sr20-952, August 30, 1943.[206]

Use: Underwater sound measurements.

Description: The transducer element consists of two rectangular tourmaline disks, ½ in. by 2 mm, which have been dipped in Aquadag to provide an electrical shield for the head. The head is then dipped in Vulcalex to protect the head and Aquadag layer. The hydrophone was tested with a one-stage preamplifier mounted in a standard C11-A1 housing, as shown in the drawing. The preamplifier is terminated by a 25-ft rubber-covered cable.

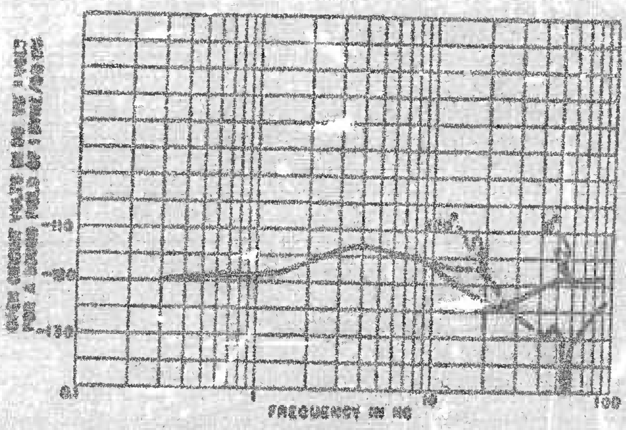

FIGURE 20. Receiving response, HT-1 hydrophone.

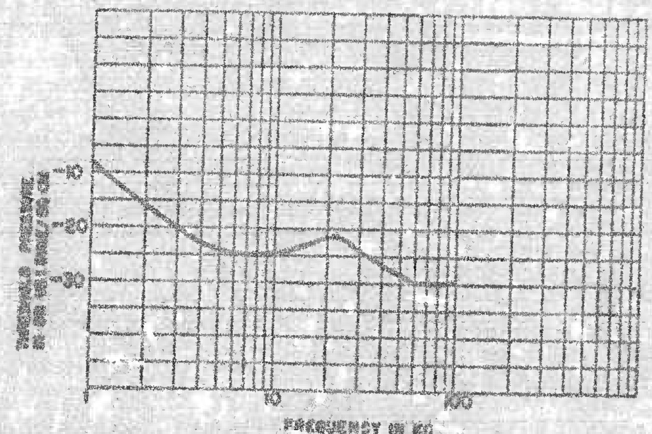

FIGURE 21. Calculated threshold, HT-1 hydrophone.

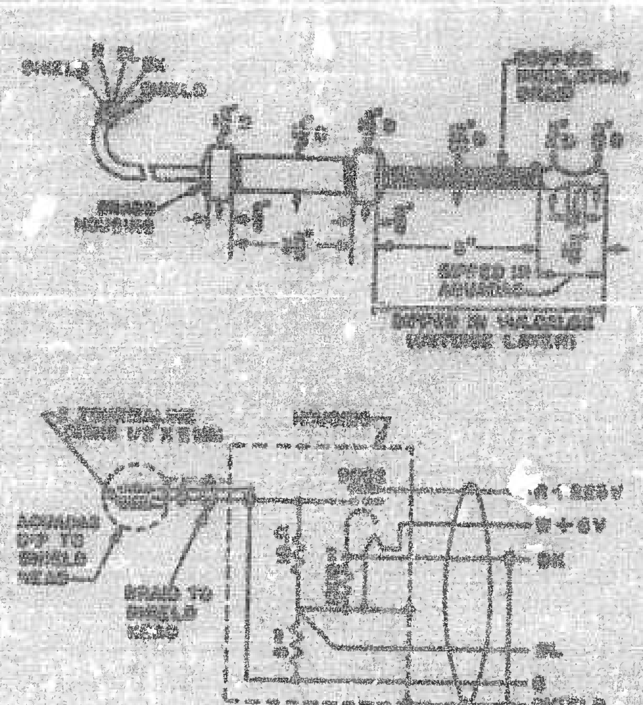

FIGURE 22. HT-1 hydrophone and preamplifier circuit.

4.1.2

Type P Hydrophone

Type: Quartz Crystal.

Reference: USRL Mountain Lakes Project No. 281B, June 5, 1944.

Use: Underwater sound measurement.

Description: The capacity of the quartz head is approximately 100 $\mu\mu f$, but it is shunted by about 1,000 $\mu\mu f$. It is associated with a two-stage preamplifier of the cathode-follower type, using a British H63 tube in the first stage and a 6J5 in the second stage. The grid resistor of the H63 is 50 megohms, but 1,000 megohms is used when the instrument is used at low frequencies.

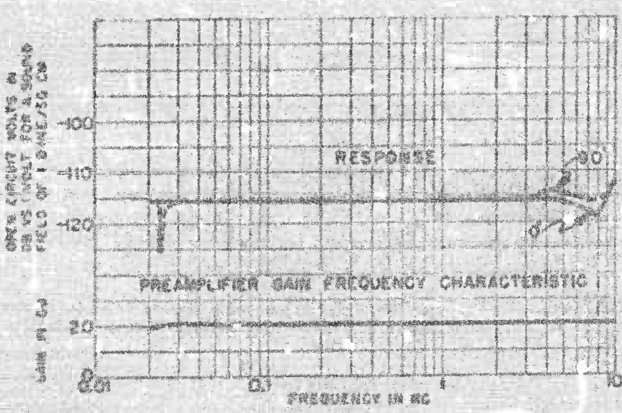

FIGURE 23. Receiving response and preamplifier gain, Type P hydrophone.

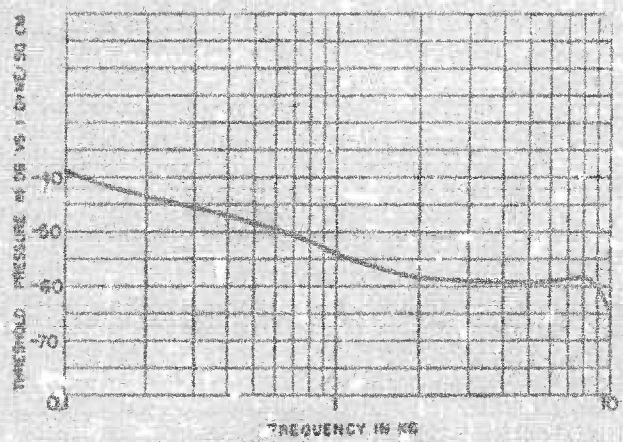

FIGURE 24. Measured threshold, Type P hydrophone.

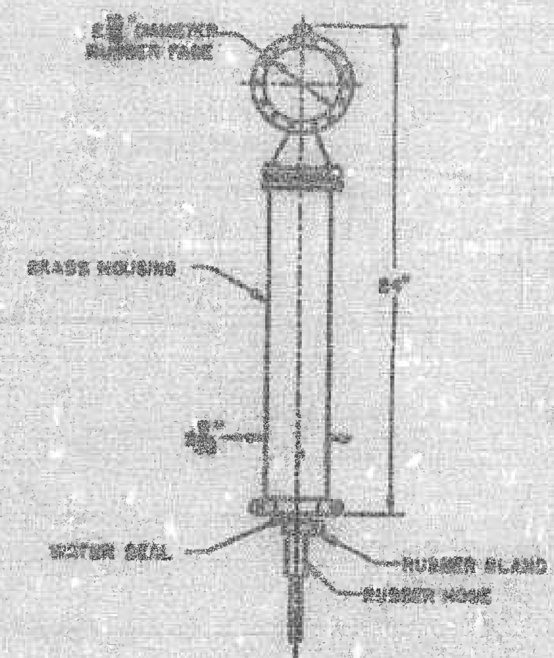

FIGURE 25. Type P hydrophone.

4.1.6 Quartz Crystal Low-Frequency Standard

Type: Quartz Crystal.
References: NDRC Report No. 6.1-sr20-619, May 6, 1943.[10]
NDRC Report No. 6.1-sr20-879, June 19, 1943.[21]
NDRC Report No. 6.1-sr1130-1364, February 4, 1944.[106]
NDRC Report No. 6.1-sr1130-1628, May 24, 1944.[108]
Use: Hydrophone standard.
Description: This device is similar to the Quartz Crystal Hydrophones No. 84 and No. 24. It uses a two-stage preamplifier of the cathode-follower type employing an H83 and L65 vacuum tube (see preamplifier circuit).

The hydrophone has two rubber-covered active faces. The crystal element is housed in a heavy bronze casting of 6-in. outside diameter. The associated preamplifier is contained in a casting to which the hydrophone is attached by a watertight connection.

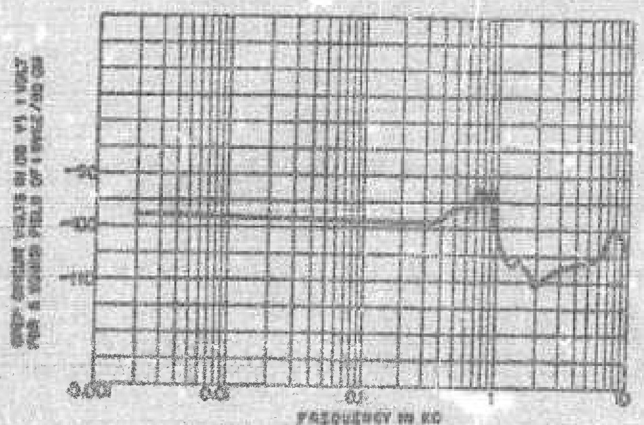

FIGURE 26. Receiving response, quartz crystal low-frequency standard.

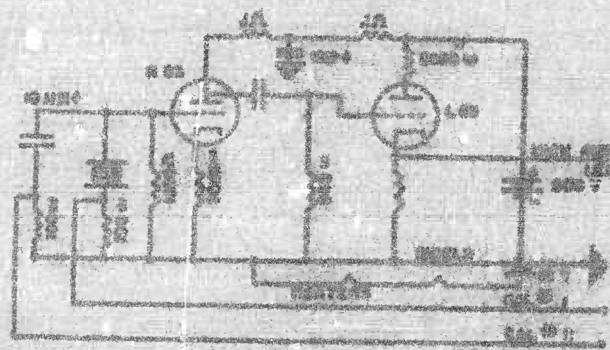

FIGURE 27. Preamplifier circuit, quartz crystal low-frequency standard.

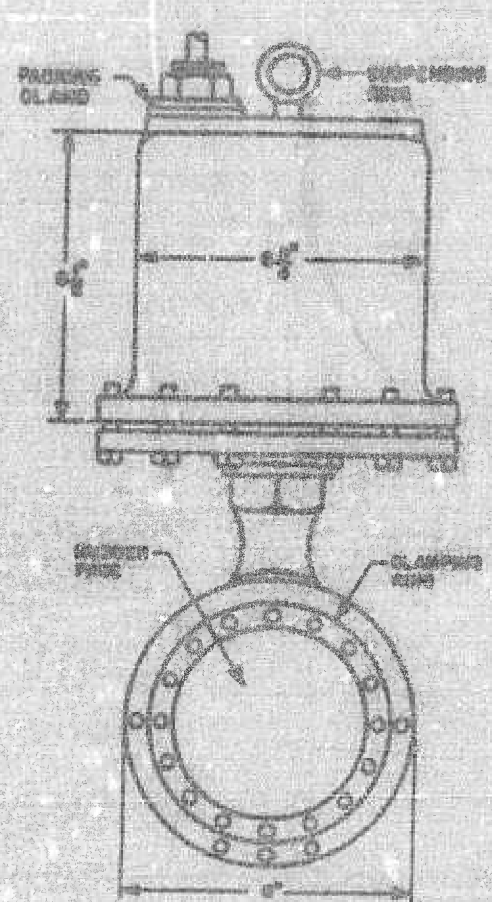

FIGURE 28. Quartz crystal low-frequency standard.

4.1.7 Canadian NRE B1 Hydrophone

Type: 45° X-Cut Rochelle Salt Crystal.

Manufacturer: Naval Research Establishment of Canada.

Reference: USRL calibration letter of July 10, 1945, to Naval Research Establishment.

Use: Underwater sound measurement.

Description: The B1 hydrophone is similar to the XMX hydrophone but is designed on a smaller scale. It is made up of four 0.035-in. thick, 45° X-cut Rochelle salt crystals in parallel. Other dimensions of crystals are approximately $\frac{1}{2} \times \frac{5}{16}$ in.

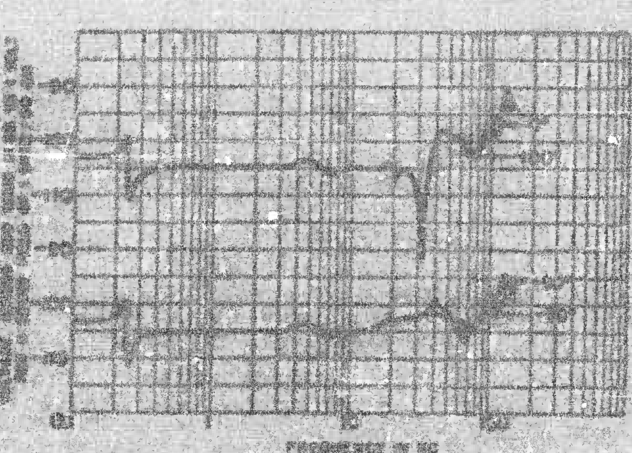

FIGURE 29. Receiving response, NRE B1 hydrophone. Water temperature = 65 F.

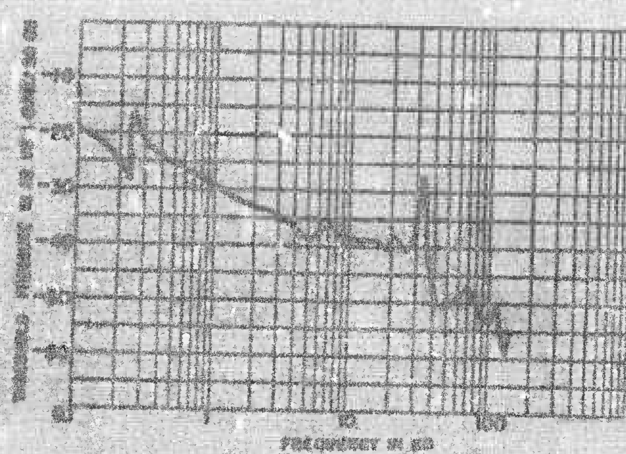

FIGURE 30. Measured threshold, NRE B1 hydrophone.

4.1.2 Canadian NRE F1 Hydrophone

Type: 45° X-Cut Rochelle Salt Crystal.

Manufacturer: Naval Research Establishment of Canada.

Reference: USRL calibration letter of July 10, 1945, to Naval Research Establishment.

Use: Underwater sound measurement.

Description: The 45° X-cut Rochelle salt crystal bank in the F1 hydrophone is the same as for the XMX hydrophone. The crystal bank is mounted in a bakelite holder ¾ in. in diameter by ⅜ in. thick.

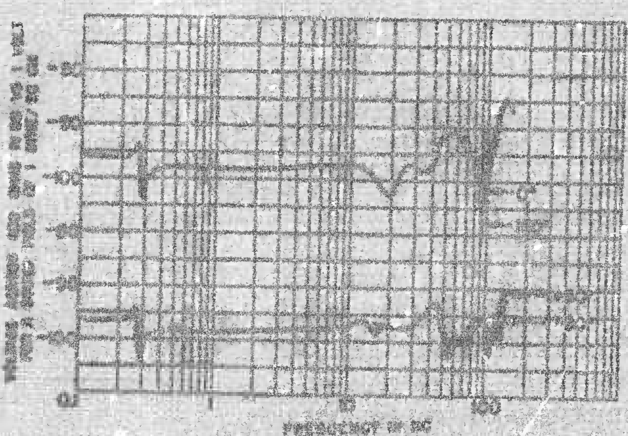

FIGURE 31. Receiving response, NRE F1 hydrophone. Water temperature = 68 F.

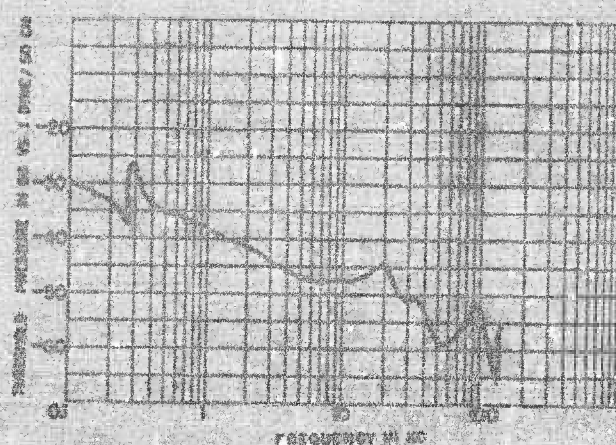

FIGURE 32. Measured threshold, NRE F1 hydrophone.

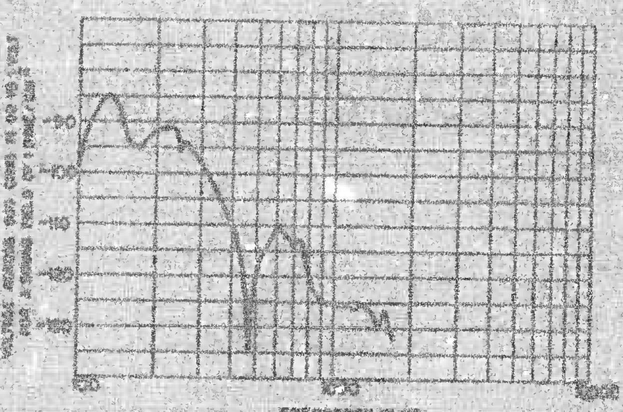

FIGURE 33. High-frequency receiving response, NRE F1 hydrophone. Water temperature = 68 F.

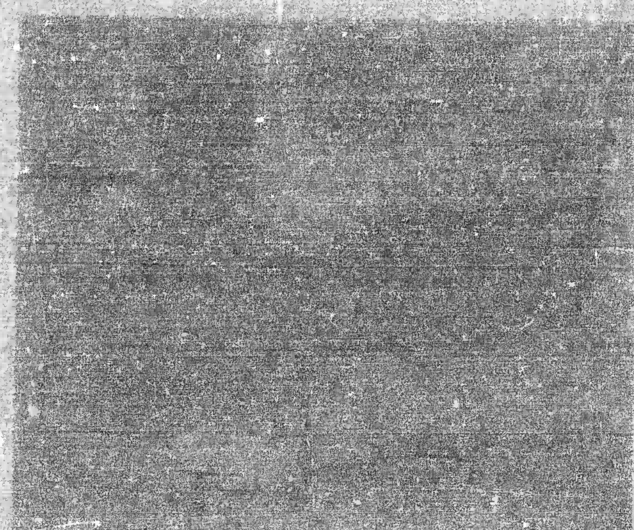

FIGURE 34. NRE F1 hydrophone.

NAVAL LABORATORIES' DESIGNS

5.1 SUMMARY

One of the primary objectives of the USRL was to assist the Navy and the various naval laboratories in their work on underwater sound equipment. A large proportion of the calibration work done by USRL was concerned with devices submitted by the Naval Research Laboratory [NRL], the Naval Ordnance Laboratory [NOL], the David Taylor Model Basin, the USS *Semmes*, the U. S. Naval Mine Warfare Test Station at Solomons, Maryland, the Bureau of Ships, and the Bureau of Ordnance. In addition, the Signal Corps General Development Laboratory, which at the beginning of the war was responsible for harbor defense, has had calibration work done by the USRL.

Much of the equipment of commercial companies such as Western Electric Company, Radio Corporation of America, and Submarine Signal Company is based on development work done by these agencies. The information as to how much of the responsibility for design was theirs is not available to the USRL in many cases, and, consequently, the devices in this report are credited to the manufacturer.

Much sonar equipment designed by NRL is in use by the Navy and is described in Chapter 2. The NRL also has developed a number of experimental units, such as the X-5 and X-6 projectors, also covered in Chapter 2. In addition, they have developed a number of hydrophone standards such as the OD, which was adopted by the USRL as one of their standards (see Chapter 1), and a low-frequency NRL design, the K type, which was used by the U. S. Naval Mine Warfare Test Station and is described in Section 5.1.1.

The USRL calibrated various hydrophones for NOL, including a number of secret devices. In the majority of cases, the acoustic units themselves were manufactured for NOL by commercial companies such as the Brush Development Company. These are listed in this volume under the manufacturer's name. The NOL, in addition, developed a velocity hydrophone standard, the SV type, a number of which were calibrated by USRL. This hydrophone is described in Section 5.1.2.

The David Taylor Model Basin submitted a number of tourmaline gauges to the USRL for calibration and these are discussed in Section 5.7. A number of special test equipments developed by the David Taylor Model Basin also were calibrated by USRL. These, however, in general employ acoustic devices of commercial manufacture and are listed herein in the manufacturer's name.

The Signal Corps General Development Laboratory at Fort Monmouth, New Jersey, has designed two GR type offshore harbor defense systems. The GR-5 unit employs twenty-four T[illegible] hydrophones. A smaller offshore unit, the GR-7, contains eight T47-T1 hydrophones. These hydrophones, as well as the systems, were developed by the Signal Corps and were tested by the USRL. These units are described in Section 5.1.4.

8.1.1

K-Type Hydrophone

Type: Tourmaline Crystal.

Designer: Naval Research Laboratory.

Reference: USRL calibration letter of July 7, 1944, to U. S. Naval Mine Warfare Test Station.

Use: For underwater sound measurements in the frequency range from 10 c to 15 kc.

Description: The transducer element is a stack of four tourmaline disks, each ⅛ in. thick and 2⅛ in. in diameter, connected electrically in parallel. The crystal stack is cemented to a brass backing plate 1⅜ in. in thickness, which in turn is backed by a cork disk ½ in. in thickness. This assembly is contained in an oil-filled steel cartridge which has a sound-transparent window of ρc rubber. The cartridge and preamplifier are mounted in an 11-in. cylindrical steel housing.

The preamplifier is two-stage with inverse feedback. The plate supply is 135 v, and the filament supply 6 v.

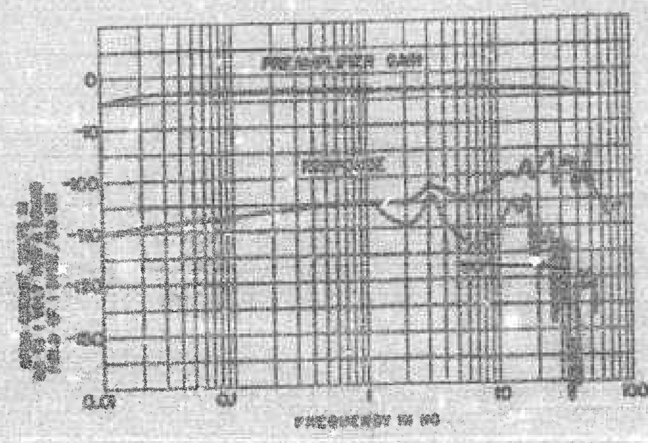

FIGURE 1. Receiving response and preamplifier gain, K-4 hydrophone.

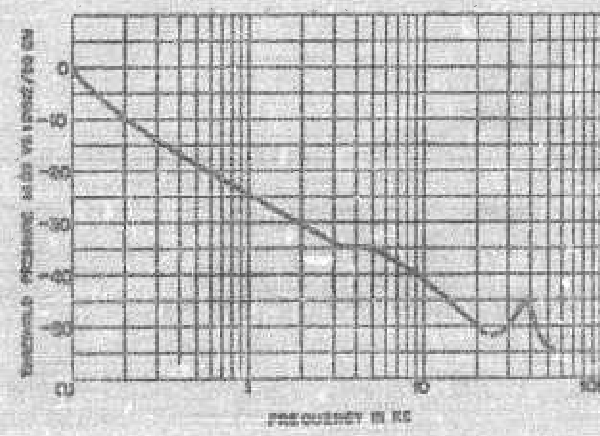

FIGURE 2. Measured threshold, K-4 hydrophone.

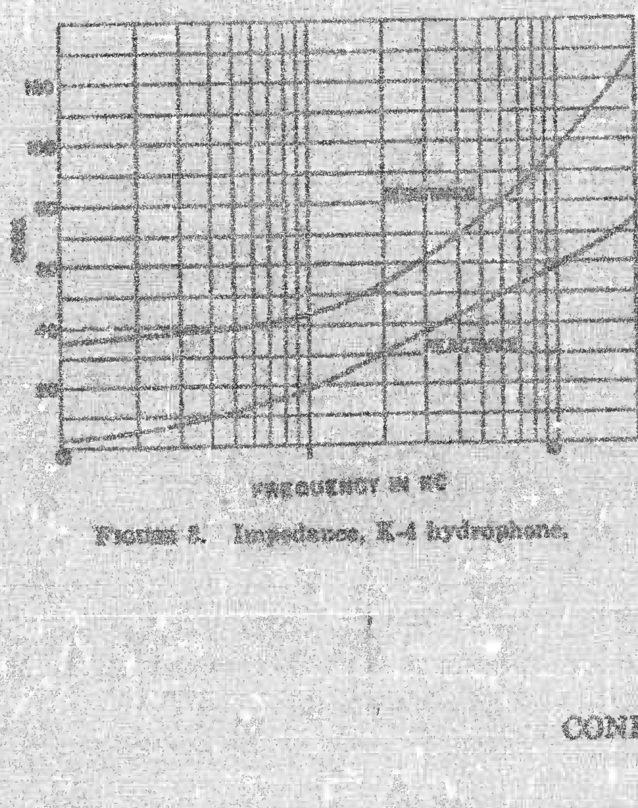

FIGURE 3. Impedance, K-4 hydrophone.

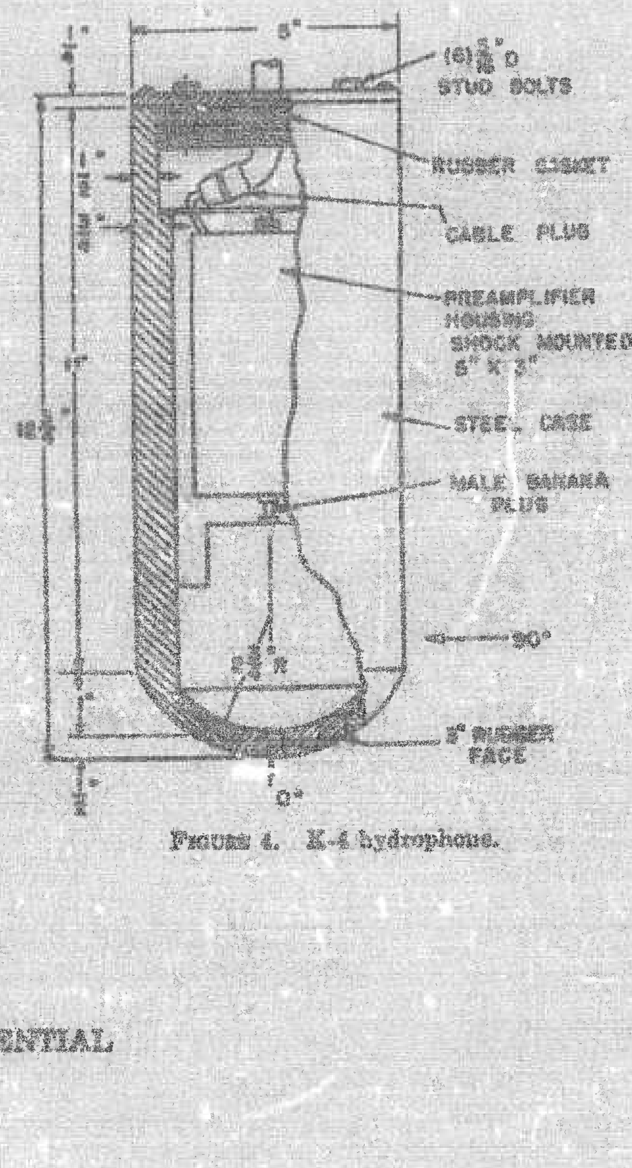

FIGURE 4. K-4 hydrophone.

8.1.2 Small Object Locator

Designer: Naval Research Laboratory.

Reference: NDRC Report No. 6.1-sr1130-1979, December 19, 1944.[118]

Use: For locating small objects in the water.

Description: The small object locator is similar to the British Asdic 135 in principle. It comprises three main parts: (1) a signal pulse generator, (2) a transducer, and (3) a tuned receiving amplifier and recorder. The unit supplied for test by USRL was equipped with a QBG projector (for characteristics see Chapter 2).

A chemical recorder similar to the British unit is provided which, for better visibility, uses a pinkish paper rather than the tan paper used in the British unit. In addition, arrangement is made for arc recording, which gives a more permanent record than the chemical recorder. The recorder has four styli instead of one in order to present more detail.

Provision is made in the small object locator for automatic volume control [AVC] and variable contrast by means of a subtraction circuit, which is similar to that in the British device.

5.1.3 SV Velocity Type Hydrophone

Type: Permanent Magnet Pressure Gradient.

Designer: Naval Ordnance Laboratory.

Reference: NDRC Report No. C4-sr20-291, October 27, 1942.[184]

Use: Low-frequency hydrophone standard.

Description: Two Duralumin hemispheres which are screwed together contain a heavy permanent magnet which is mounted flexibly on soft rubber. A coil is rigidly mounted on this sphere. The sphere and the coil partake of the velocity of the sound at low frequencies. Thus a relative motion is obtained between the coil and the magnet, generating alternating voltages in the coil. In order that the sphere move with the sound, the wavelength of the sound must be considerably longer than the diameter of the sphere, which is 2⅝ in. This limits the response of the instrument to frequencies below 10 kc.

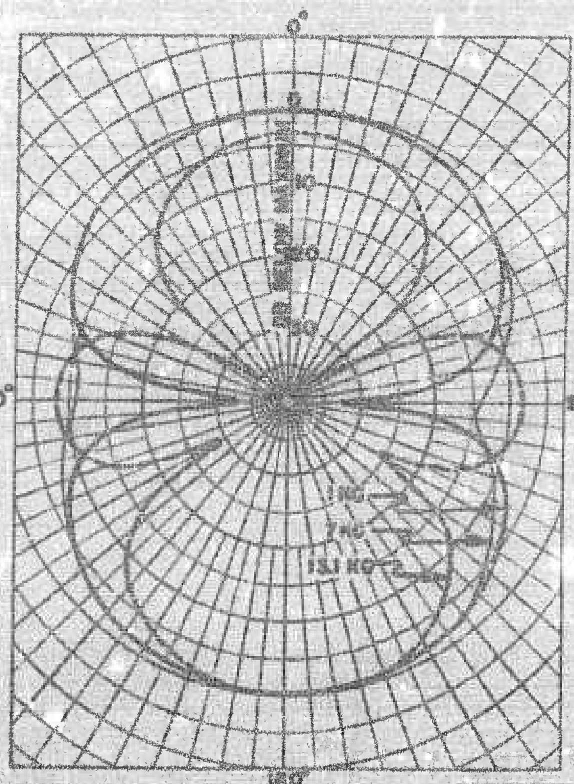

FIGURE 5. Directivity patterns, SV hydrophone.

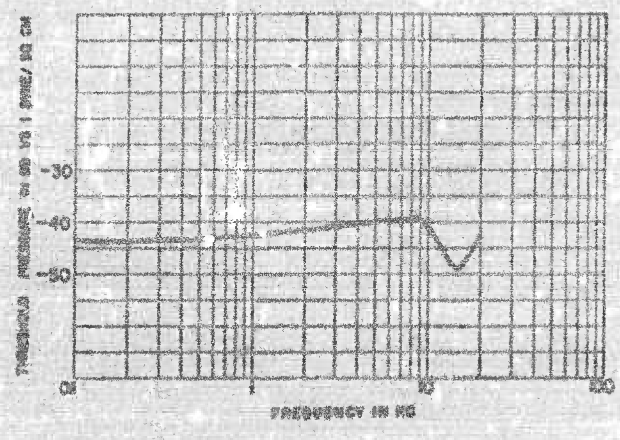

FIGURE 7. Calculated threshold, SV hydrophone.

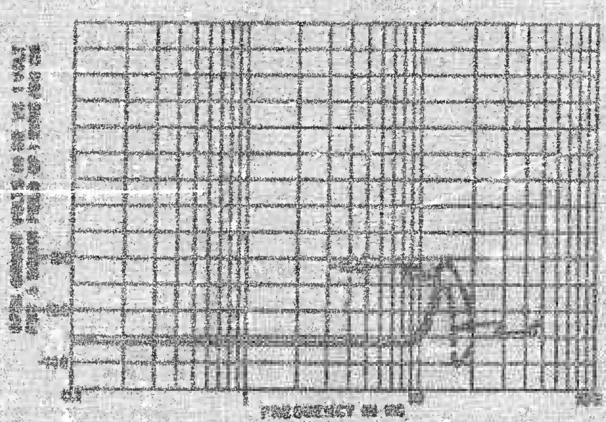

FIGURE 6. Receiving response, SV hydrophone.

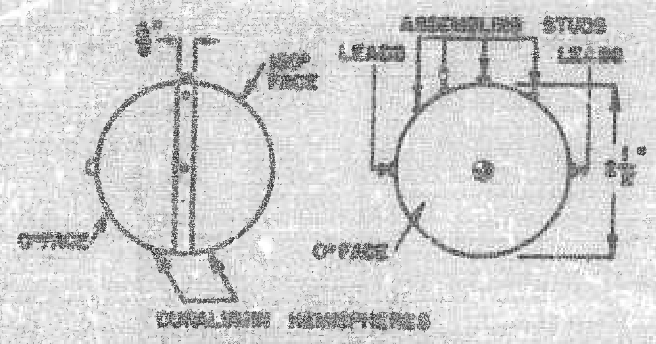

FIGURE 8. SV hydrophone.

3.1.4 T22 and T37-T1 Hydrophones

Type: Moving Coil Permanent Magnet.

Designer: Signal Corps General Development Laboratory, Fort Monmouth, New Jersey.

Reference: NDRC Report No. C4-sr20-294, November 13, 1942.[113]

Use: In GR-5 and GR-7 offshore harbor defense units.

Description: The two types of hydrophone are identical in principle but differ in size, the T37-T1 being one-half the size of the T22. The outer wall of the cylinder, which is of Alsiko steel, constitutes the permanent magnet of the hydrophone. A tube through the center of the cylinder connects the two diaphragms in an assembly somewhat like a "dumbbell." A coil, located in the air gap of the magnetic circuit, is fastened to one of the diaphragms.

The GR-5 system employs twenty-four T22 hydrophones. The GR-7 offshore unit, which is a small edition of the GR-5, contains a row of eight T37-T1 hydrophones. Four of these are spaced at 1-ft intervals in each half of the beam. The beam is capable of being rotated through 180° in the horizontal plane. The systems are designed for binaural listening at audio frequencies, the hydrophones in the left half of the beam being connected through suitable amplifiers and receivers to the left ear, and those in the right half to the right ear of the observer.

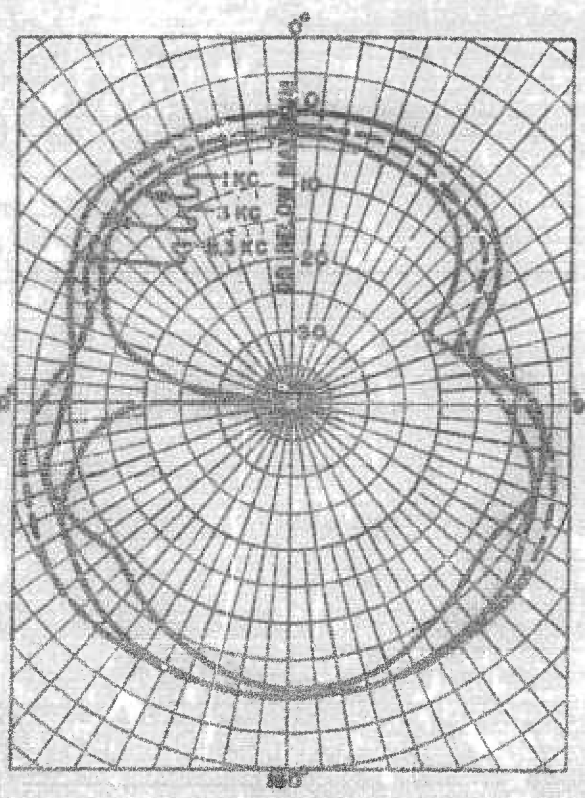

FIGURE 9. Directivity patterns, T22 hydrophone.

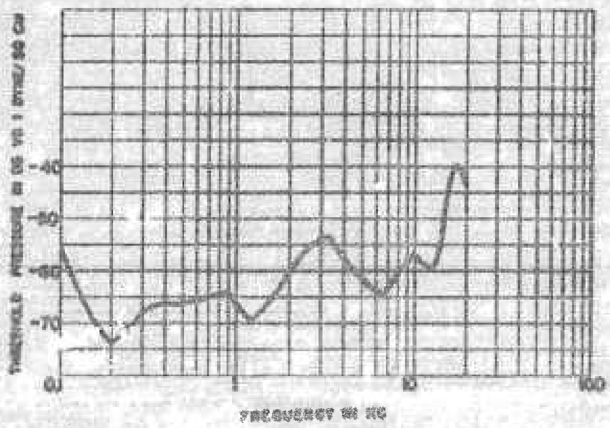

FIGURE 11. Calculated threshold, T22 hydrophone.

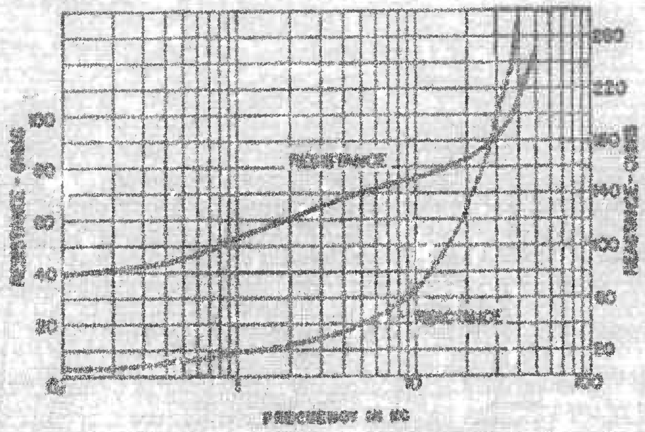

FIGURE 12. Impedance, T22 hydrophone.

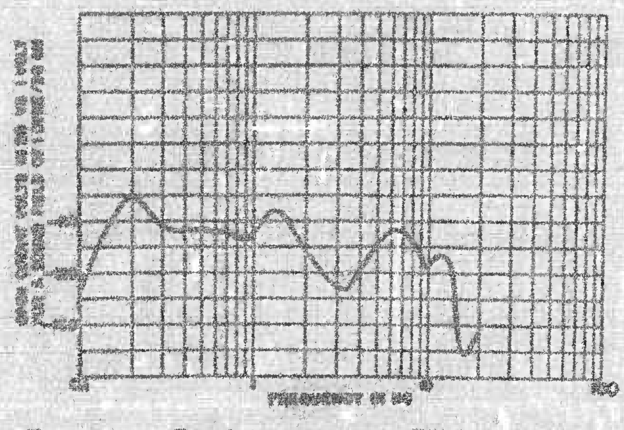

FIGURE 10. Receiving response, T22 hydrophone.

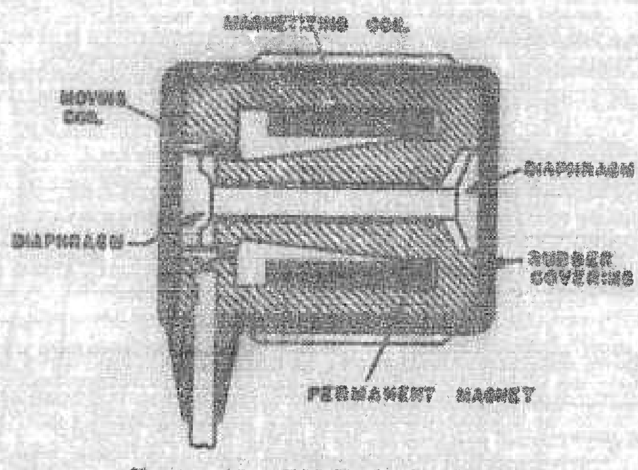

FIGURE 13. T37-T1 hydrophone.

Chapter 6

NDRC DIVISION 6.1 DESIGNS

6.1 INTRODUCTION

This chapter covers the underwater acoustic instruments designed and, in most cases, built by laboratories established by Division 6 of the National Defense Research Committee [NDRC]. For the most part only devices calibrated by the USRL have been included, although some additional instruments are described. The designs of the following laboratories are included: Columbia University Division of War Research at the U. S. Navy Underwater Sound Laboratory, New London [CUDWR-NLL], Harvard Underwater Sound Laboratory [HUSL], Massachusetts Institute of Technology Underwater Sound Laboratory [MIT-USL], and University of California Division of War Research at the U. S. Navy Radio and Sound Laboratory, San Diego [UCDWR]. In addition, two of the NDRC projects in which the USRL has been actively engaged over an extended period of time are described in individual sections so as to provide a unified picture of the work done in connection with them. These projects are: (1) Tourmaline gauges, which include designs by the David Taylor Model Basin [DTMB] and the Stanolind Oil and Gas Company. (2) Scanning sonar systems.

6.2 INSTRUMENTS DESIGNED AND CONSTRUCTED BY COLUMBIA UNIVERSITY

This section describes the hydrophones that were calibrated by the USRL for Columbia University, Division of War Research, at the U. S. Navy Underwater Sound Laboratory, Fort Trumbull, New London, Connecticut.

One of the main design efforts of the New London laboratory has been the development of magnetostriction listening units, although the attention of the laboratory, of course, has by no means been confined to these units. A variety of crystal hydrophones have been used for listening and other purposes, but usually these were adopted from designs by other agencies, especially the Brush Development Company of Cleveland, Ohio.

The magnetostriction principle of design was advocated by the New London laboratory because it permitted the construction of inherently simple and rugged units. The same considerations led the U. S. Navy to adopt, in pre-war days, magnetostriction echo-ranging projectors. The trend in echo ranging has been away from magnetostriction and toward crystal devices. The reasons, as outlined in Chapter 2, are (1) improvements in crystals (Y-cut Rochelle salt and especially ADP) and (2) the higher output and efficiency obtainable with crystals. For listening devices, the advantages, if any, of crystals are less pronounced. The difficulties of having crystals respond well at the lower audio frequencies are well known, and at those frequencies there is probably little choice between the two types of transducers from the efficiency standpoint. Furthermore, for listening, efficiency is less important since added gain in the receiving amplifier can compensate for it, provided the threshold of the hydrophone is sufficiently low. The latter, theoretically at least, can be reduced to any desired value by increasing the size of the unit. This can readily be done for the New London designs by extending their length.

Below resonance the hydrophone response of magnetostriction underwater sound devices increases with frequency. It can be shown that this is an inherent characteristic of magnetostriction. The added flux caused by magnetostriction is proportional to the pressure:

$$\theta = Cp + \theta_0,$$

where θ is the total flux, p is the pressure, C is the proportionality constant, and θ_0 is the flux that would exist if the material were not magnetostrictive.

The induced voltage then is proportional to the rate of change of the flux, so that

$$e_0 = j\omega Cp = C'fp,$$

where $\omega = 2\pi f$ and C' = proportionality con-

stant. On the basis of the ship's sounds and the background noise decreasing with frequency, this increase in response has been considered advantageous by the New London laboratory.[132]

Magnetostriction designs generally are of low impedance. From the standpoint of the maximum permissible length of cable that can be attached to the hydrophone without excessive loss or noise pickup, the low impedance of the magnetostriction devices as compared to crystal units presents a real advantage. In many cases it obviates the need for an underwater preamplifier.

The New London magnetostriction devices are invariably "line hydrophones." A line has maximum response in all directions normal to the axis, but the piston's response is unidirectional and sharp discrimination exists between the pickup of sound from the front and rear of the device. Offhand, this discrimination on the part of the piston would appear to be of considerable advantage in locating objects by listening. Since, however, this discrimination depends on the ratio of the wavelength and the diameter of the piston,[160] a very large piston is required to provide substantial discrimination at low frequencies. For instance, in order to have a discrimination of 10 db at 500 c, a piston must have a diameter of no less than 4 ft.

Several methods have been used by the New London laboratory to provide front and rear discrimination for the line hydrophones. These methods in general consist in using baffles[142] to reduce response on one side of the hydrophone, or in using two units[129] connected in such a way to a phasing network that their output is combined when the sound comes from one direction and tends to cancel when the sound comes from the opposite direction (see Section 6.6.5).

Figure 1 shows a directivity pattern for a continuous line, and Figure 2 for a theoretical piston. The one is expressed in terms of the length in wavelengths and the other in terms of the diameter in wavelengths. It will be noted that, for the same maximum dimensions, the line has a narrower beam width but the piston has lower side lobes. There has been much discussion concerning any possible advantages for listening inherent in the narrow beam of the line hydrophone and any possible advantages due to the lower side lobes of the circular piston. It is, of course, possible to change these factors by "tapering" or its inverse, so that actually these differences may not be so important. Tapering has been used in a number of New London designs to reduce the magnitude of the side lobes of their line hydrophones.[156]

The following are some of the principal applications of magnetostriction hydrophones that have been made by the New London laboratory.

1. Tubular magnetostriction hydrophones have been used for harbor defense.[132] These hydrophones were designed for the audio frequency range and consisted of a nickel tube in which a longitudinal coil with laminated core was located. The tube is permanently magnetized by means of the coil, the flux passing through the coil and returning through the two sides of the tube. (See Figure 3.) The usual length for these hydrophones was 4 ft and 6 ft.[155] These units were hung vertically in the water to detect any approaching surface vessel or submarine (see Section 6.6.5).

2. In order to better define the direction of sound pickup, a toroidal magnetostriction hydrophone was developed by the New London laboratory. (See Figure 4.) Since a torus usually is bidirectional, methods for discriminating against rear response were applied to this unit. These consisted of using a baffle or a system combining two identical units with a phasing network.[127] (See Section 6.6.5.)

3. In order to improve the efficiency of the design, a wood core was used, cylindrical in contour, and closely conforming to the internal diameter of the nickel tube. The hydrophone coil is wound over this wood cylinder, which also positions the iron core. This type of construction is used in the JP listening unit. (See Figure 5.)

4. Further development of the magnetostriction hydrophone resulted in a toroidally wound cylindrical hydrophone (Figure 6). This type of design was finally adopted by the New London laboratory, and practically all later New

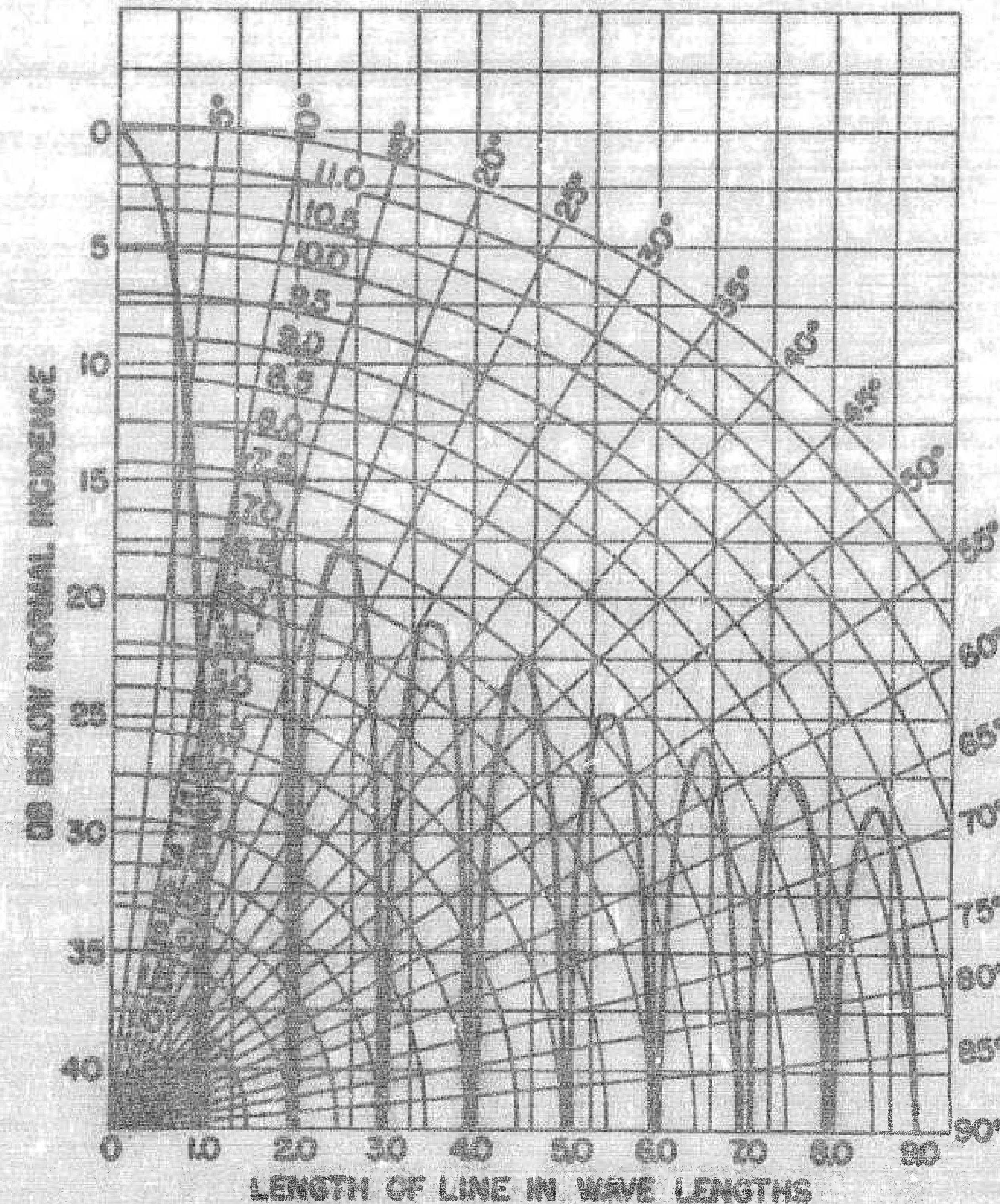

FIGURE 1. Directivity pattern for a continuous line.

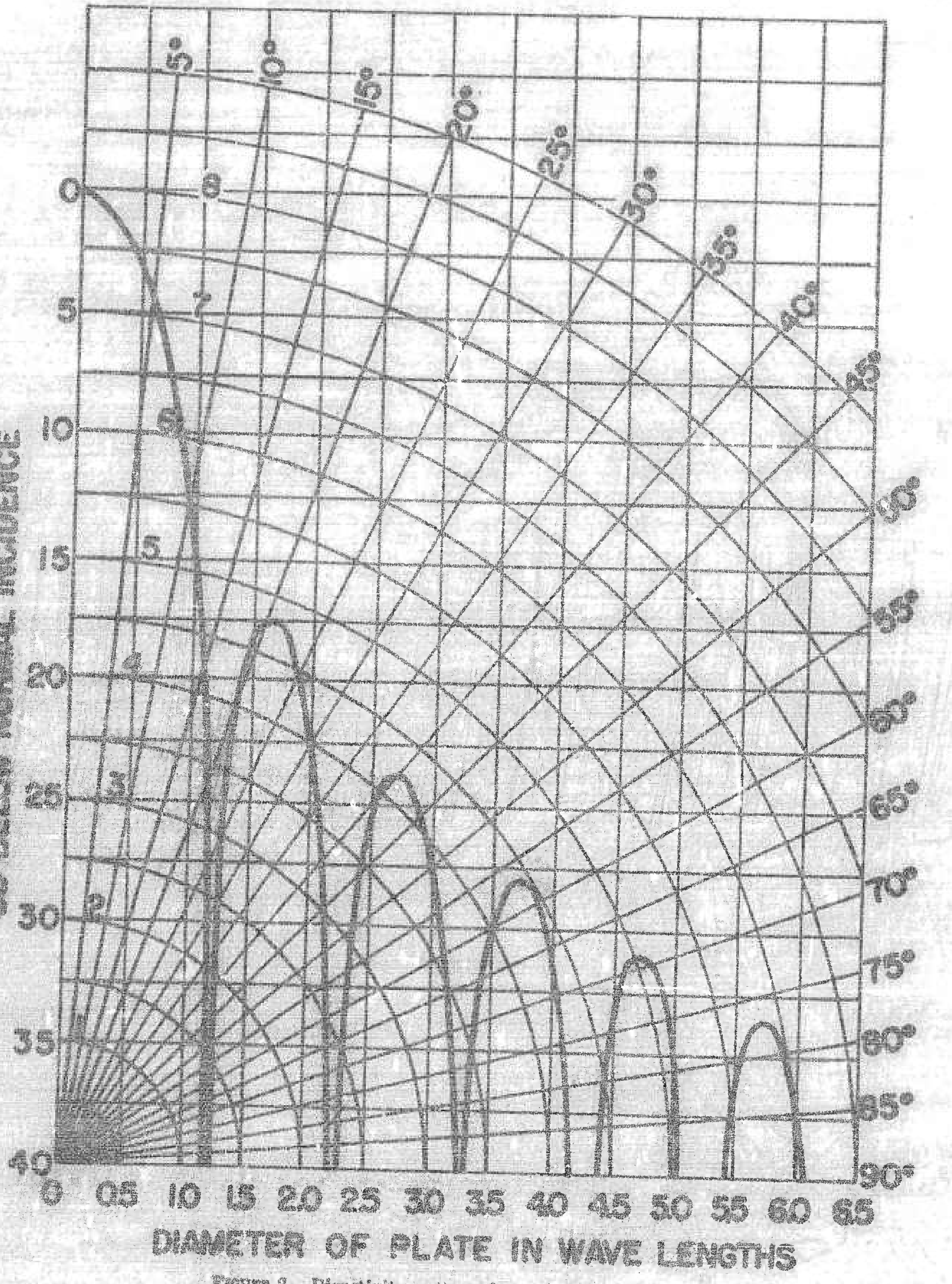

FIGURE 2. Directivity pattern for a circular plate.

London designs were of that construction. The D-16 Mark IV hydrophones are examples of this design (see Section 6.6.1). Two section units about 2 ft in length, equipped with a baffle to provide rear discrimination, are used in the Directional Radio Sono Buoy developed by the New London laboratory.[154]

5. A 37-in. magnetostriction line hydrophone has been adopted for the U. S. Navy JP listening equipment for listening from submarines, COG 51058.[143] A further improvement in this equipment resulted in the design of the model JT sonar equipment by the New London laboratory. This uses the NL-124 magnetostriction unit, which consists of ten sections of permanent magnet units toroidally wound. The design is tapered for side lobe reduction and includes a baffle for rear response reduction.[136] (See Section 6.6.3.)

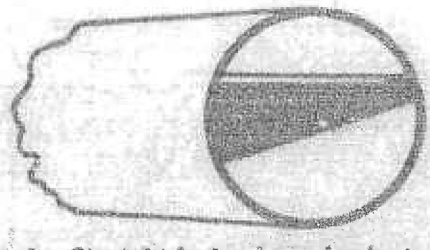

Figure 3. Straight hydrophone, laminated core.

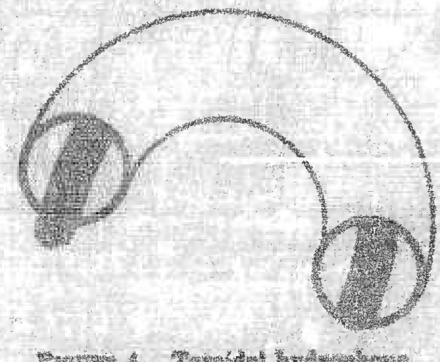

Figure 4. Toroidal hydrophone.

6.3 INSTRUMENTS DESIGNED AND CONSTRUCTED BY HARVARD UNIVERSITY

The instruments designed and built by the Harvard Underwater Sound Laboratory which have been calibrated by the USRL are: B19-B, B19-H, HP-4, Sword Arm, CR Sonar, and ED Sonar. The B19-B and B19-H are used as USRL standard hydrophones and are covered in Sections 1.4.14 and 1.4.15. The Sword Arm and HP-4 are experimental models designed for Navy use and are discussed in Sections 2.7.46 and 2.7.47. The scanning sonars are discussed in Section 6.8.

6.4 INSTRUMENTS DESIGNED AND CONSTRUCTED BY THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Instruments designed and built by the Underwater Sound Laboratory at the Massachusetts Institute of Technology and calibrated by the USRL are discussed herein. The tourmaline gauges are included in Section 6.7.3 and the CMF, HK types, and XMX hydrophones which were used as USRL standards are to be found in Sections 1.4.18, 1.4.19, and 1.4.21, respectively. In addition, the XPA, HU, and HP (used with the PAR sound level indicator) are contained in Sections 6.6.9, 6.6.8, and 6.6.7 respectively.

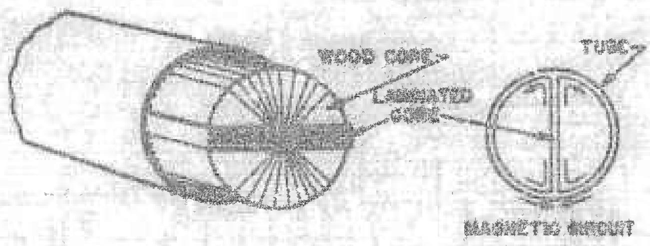

Figure 5. Straight hydrophone, laminated core with additional wood core.

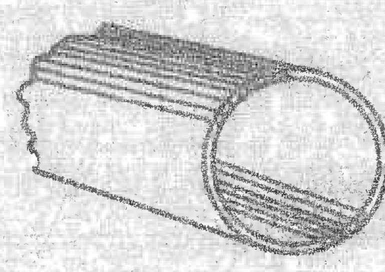

Figure 6. Straight toroidally wound hydrophone.

Various types of electroacoustic coupling were employed in the MIT designs to obtain devices for special uses, in particular for measurement of noise sources, noisemakers, and ex-

plosive sounds. These applications required low-sensitivity devices with a low-frequency response and mechanical strength to withstand high pressure. The tourmaline gauges satisfied these requirements. The HU is also a low-sensitivity device with mechanical strength. The CMF which has a good low-frequency response can also be used to obtain absolute calibrations. The HP hydrophone and PAR sound level indicator were used for calibration as well as measurements.

6.8 INSTRUMENTS DESIGNED AND CONSTRUCTED BY THE UNIVERSITY OF CALIFORNIA

The instruments described in this chapter were selected by the University of California, Division of War Research as representative of the transducers designed by that division. Included in this selection are some instruments which were not calibrated by the USRL. In this case, UCDWR calibrations are used. Other instruments representing older types were omitted from the selection even though they had been calibrated by the USRL. The origin of the data used herein, of course, is clearly shown by the references given in each case. The following are types which were calibrated by the USRL but are not included in the selection presented herein:

BD1: NDRC Report No. 6.1-sr20-614, March 30, 1943.[133]

CD1: NDRC Report No. 6.1-sr20-614, March 30, 1943.[133]

CY4: NDRC Report No. 6.1-sr1130-1637, July 17, 1944.[146] (CY4 Sample 3A is described in Section 6.6.11.)

The FM Scanning Sonar, which is also a UCDWR development, is described in Section 6.8.3.

The UCDWR had one group at San Diego which was engaged in the design of instruments mostly of the piezoelectric type. All the instruments covered herein use either ADP or Rochelle salt crystals for the active elements. Special designs were obtained by varying the size and number of crystals, and by "shading" to improve directivity.

The UCDWR also operated an underwater sound calibration station at Sweetwater about 5 miles from San Diego. The calibrations of their devices given herein, other than the USRL calibrations, were obtained by the UCDWR at Sweetwater.

6.6 NDRC DIVISION 6.1 INSTRUMENTS

6.6.1 D-16 Mark IV-D Hydrophone

Type: Magnetoctriction.
Operating range: 200 c to 60 kc.
References: NDRC Report No. 6.1-sr20-865, July 7, 1943.[189]
NDRC Report No. 6.1-sr20-871, May 14, 1943.[193]
NDRC Report No. 6.1-sr1130-1108, December 17, 1943.[161]
Use: Sound element in expendable nondirectional radio sono buoy.

Description: Upon a cylindrical tube of unannealed nickel, a coil is closely wound in such a manner that half of each turn is adjacent to the inner wall and the other half adjacent to the outer wall. The so-called "tomato can" (see Figure 11) has a diameter of approximately 3 in. and a length of 5 in. The type of insulation used between the turns and the tube depends on the wire. In one example, the space between the winding and the tube was filled with rubber, in another case, with Lucite. Precautions are taken in the manufacture to avoid air bubbles between the tube and winding.

Experimental models, the so-called "A" type hydrophones, were constructed to study the effect on directivity of air cell rubber inside the winding.

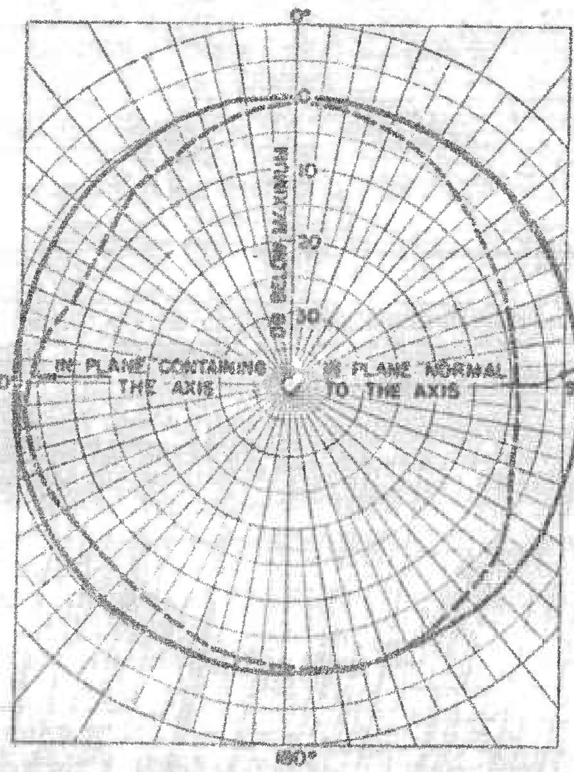

FIGURE 7. Directivity pattern, D-16 Mark IV-D hydrophone at 9.6 kc.

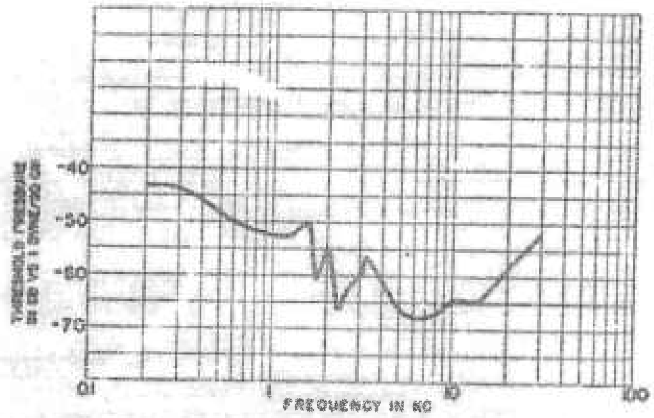

FIGURE 9. Calculated threshold, D-16 Mark IV-D hydrophone.

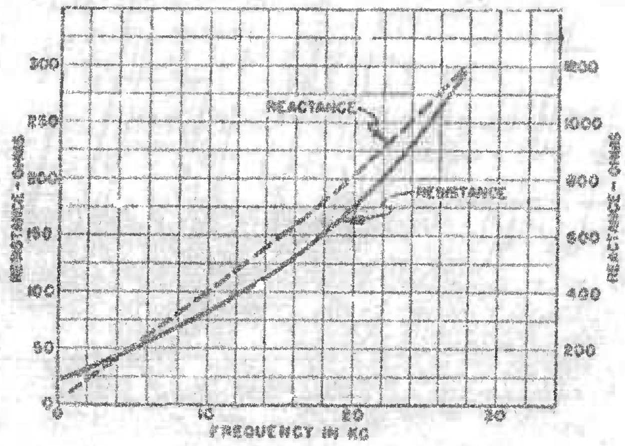

FIGURE 10. Impedance, D-16 Mark IV-D hydrophone.

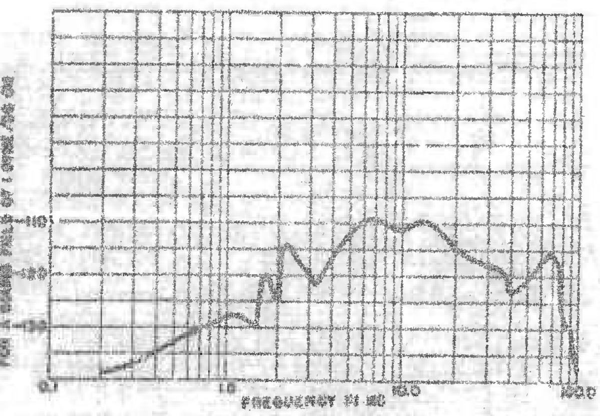

FIGURE 8. Receiving response, D-16 Mark IV-D hydrophone.

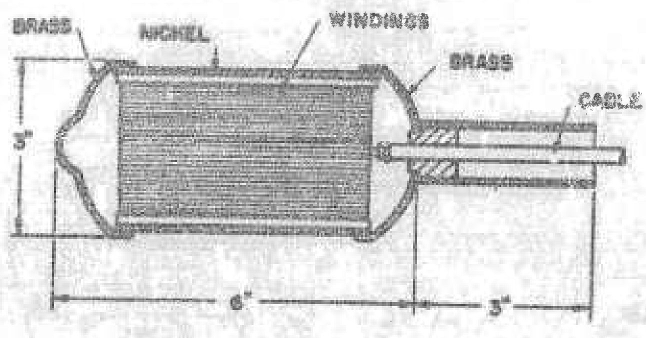

FIGURE 11. D-16 Mark IV-D hydrophone.

4.4.2 JP Hydrophone (COG 51053)

Type: Magnetostriction.
Operating range: Audio frequencies.
Manufacturer: Astatic Corporation, Youngstown, Ohio.
References: NDRC Report No. 6.1-sr1130-1163, February 2, 1944.[142]
NDRC Report No. 6.1-sr20-942, July 22, 1943.[55]
UCDWR Report No. C17, November 8, 1943.[138]
Use: In JP-1 listening system.
Description: The JP hydrophone is of the straight wood core magnetostriction type. The unit consists of a nickel cylinder about 40 in. in length and 2 in. in diameter, in which a cylindrical wood core extends most of the length. The coil is wound on this core with the turns running parallel to the axis of the tube. Across the diameter of the tube, cutting the wood core in half and extending the length of the tube, is a laminated core. A streamlined rubber-covered baffle provides directivity.

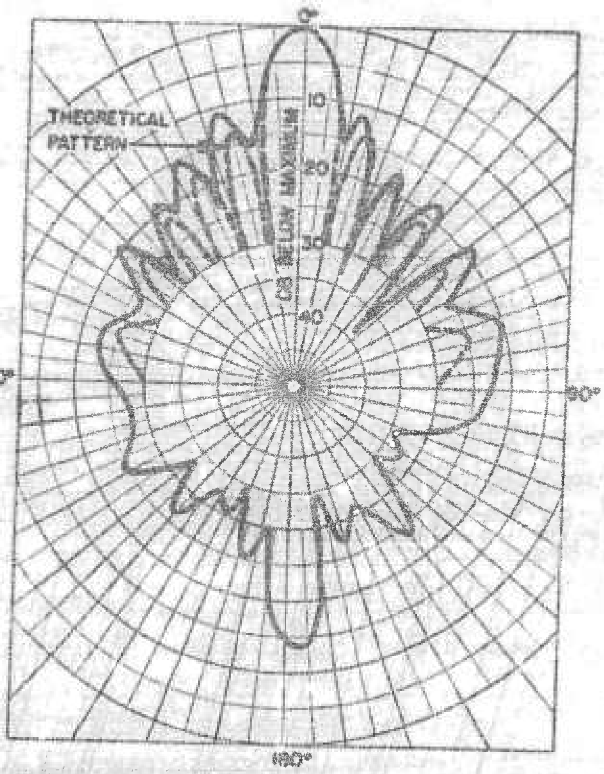

FIGURE 12. Directivity pattern, JP (COG 51053) hydrophone at 10 kc.

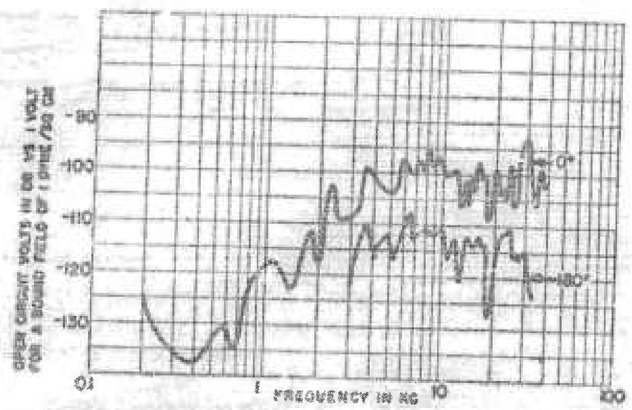

FIGURE 13. Receiving response, JP (COG 51053) hydrophone.

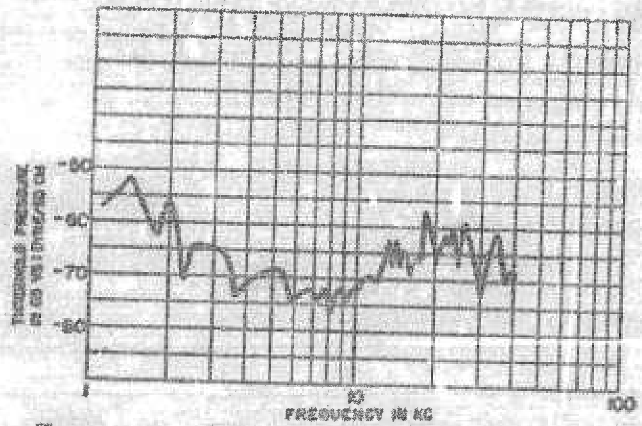

FIGURE 14. Calculated threshold, JP (COG 51053) hydrophone.

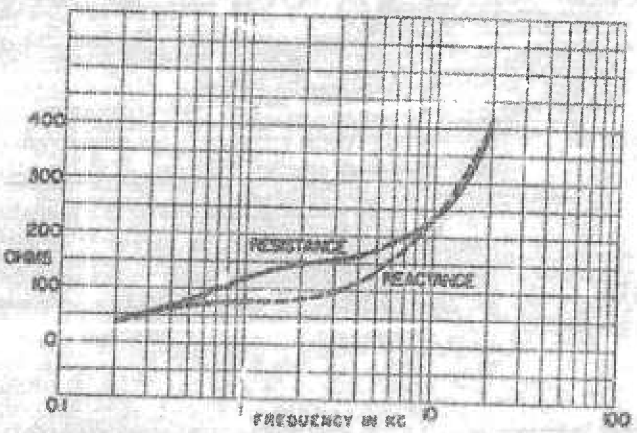

FIGURE 15. Impedance, JP (COG 51053) hydrophone.

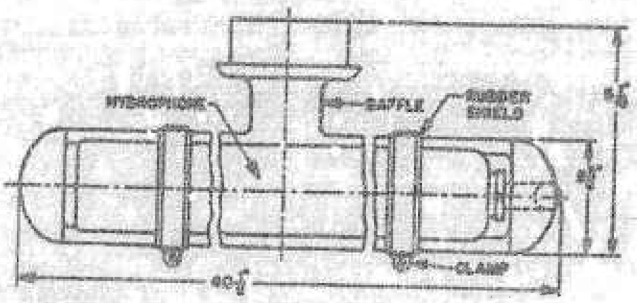

FIGURE 16. JP hydrophone assembly (COG 51053).

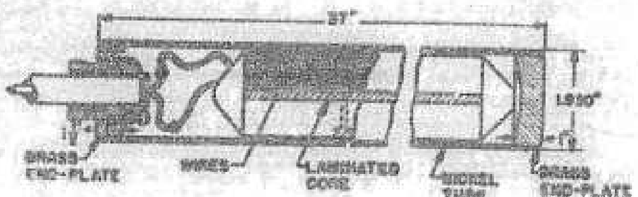

FIGURE 17. Cross-sectional view of magnetostriction unit, JP (COG 51053) hydrophone.

6.6.3 NL-124 Hydrophone (CQA 51074)

Type: Magnetostriction.
Operating range: 100 c to 65 kc.
References: NDRC Report No. 6.1-sr1130-2185, February 12, 1945.[151]
NDRC Report No. 6.1-sr1128-2215, May 25, 1945.[156]
Use: For JT sonar equipment.

Description: The NL-124 hydrophone is a 5-ft permanent magnet magnetostriction line, consisting of 10 sections which are tapered to reduce side lobes. The sections are toroidally wound. The hydrophone is plastic-filled and covered with neoprene rubber compound. A 4-wire cable permits the use of separate channels for the two halves. The hydrophone is 60 in. long, 2½ in. in diameter, and weighs approximately 22 lb. A 129-A baffle is used with the hydrophone to provide front-to-back discrimination.

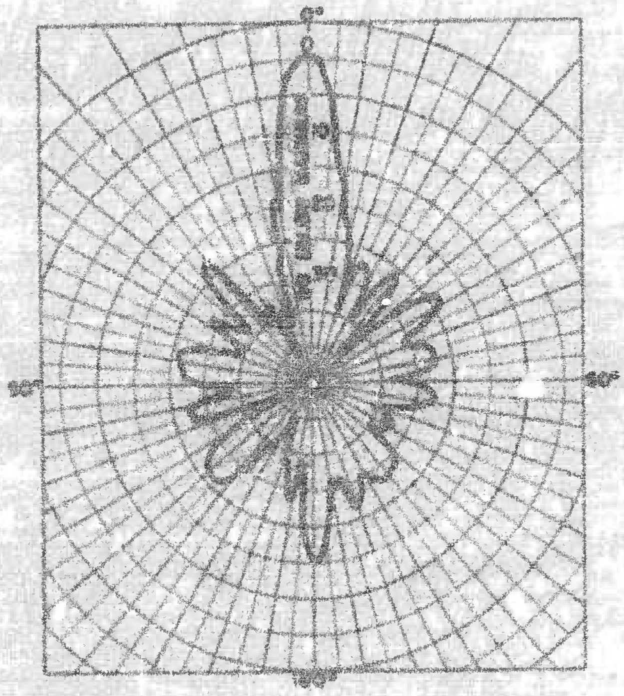

FIGURE 18. Directivity pattern, NL-124 hydrophone at 9.5 kc (series aiding).

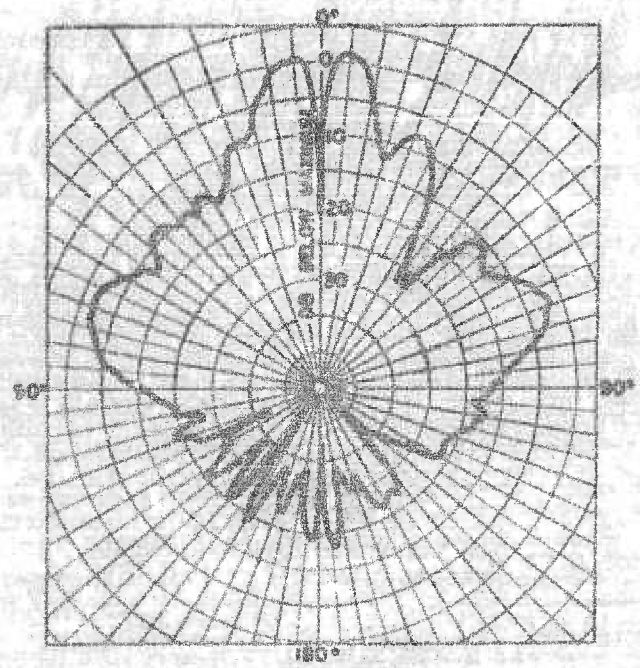

FIGURE 19. Directivity pattern, NL-124 hydrophone at 9.5 kc (series opposing).

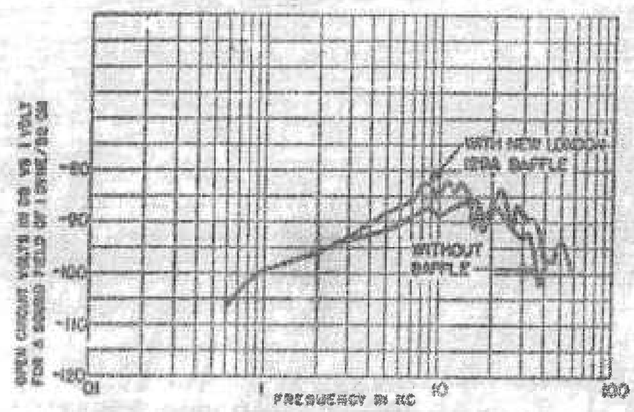

FIGURE 20. Receiving response, NL-124 hydrophone.

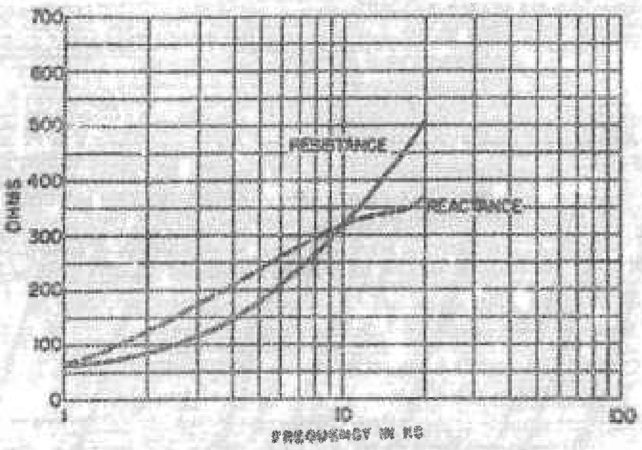

FIGURE 22. Impedance, NL-124 hydrophone.

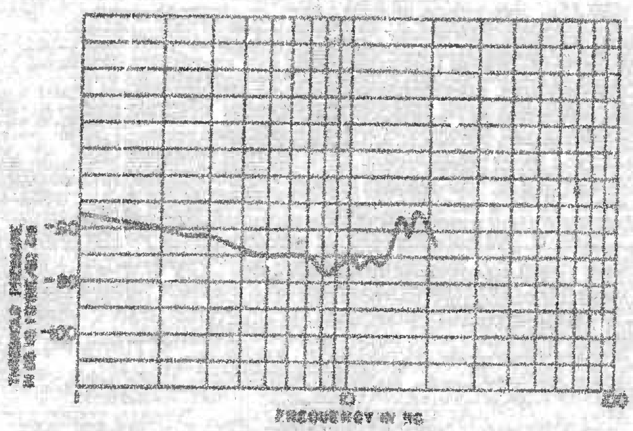

FIGURE 21. Calculated threshold, NL-124 hydrophone with baffle.

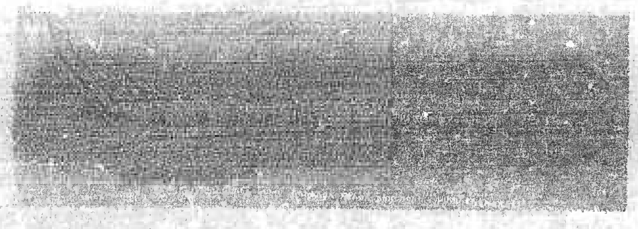

FIGURE 23. NL-124 hydrophone with NL-129-A baffle.

6.6.4 NL-130 Hydrophone

Type: Magnetostriction.

Operating range: 200 c to 60 kc.

Manufacturer: Astatic Corporation, Youngstown, Ohio.

Reference: NDRC Report No. 6.1-sr1130-1838, October 19, 1944.[149]

Use: In noise level monitoring installations and for the depth charge indicator.

Description: The NL-130 hydrophone is a magnetostriction device in which the permanent magnet transducer element is contained in a 10⅛ in. by 2½ in. rubber cover with sealed polystyrene end fittings. The device is vacuum-filled with a phenolic resin composition which is polymerized to form a hard elastic solid. The transducer element consists of a heat-treated nickel tube. An Alnico magnet is silver-soldered into a slot in this tube. A toroidal winding having 270 turns of No. 27 gauge wire is applied to the nickel tube. A wooden dowel inside the tube furnishes a pressure release. A special feature of this hydrophone is its mechanical ruggedness, which makes it suitable for use at great depth.

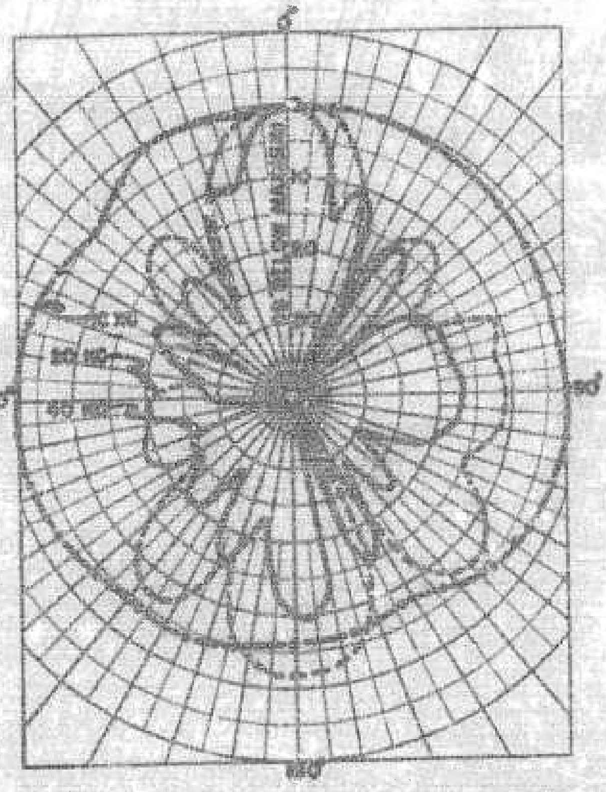

FIGURE 24. Directivity patterns, NL-130 hydrophone.

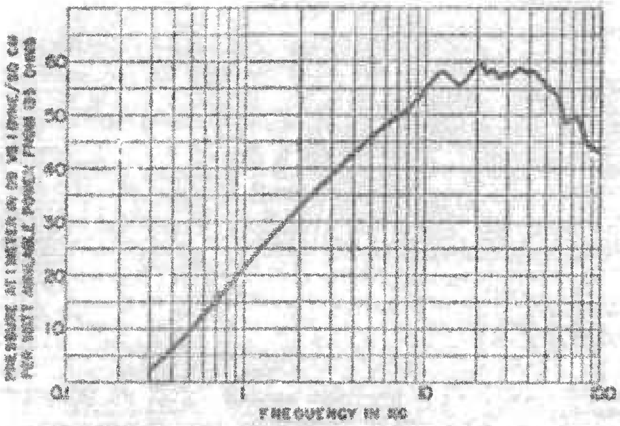

FIGURE 25. Transmitting response, NL-130 hydrophone.

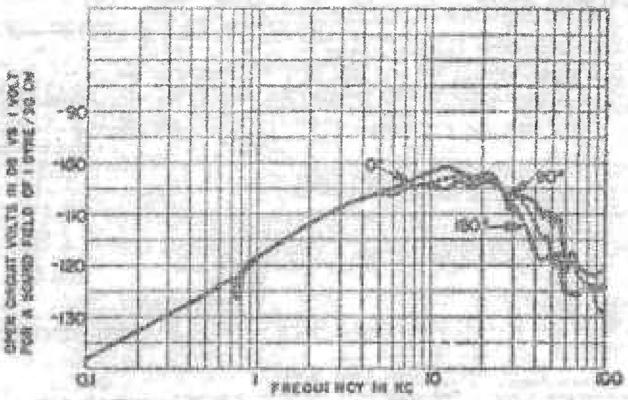

FIGURE 26. Receiving response, NL-130 hydrophone.

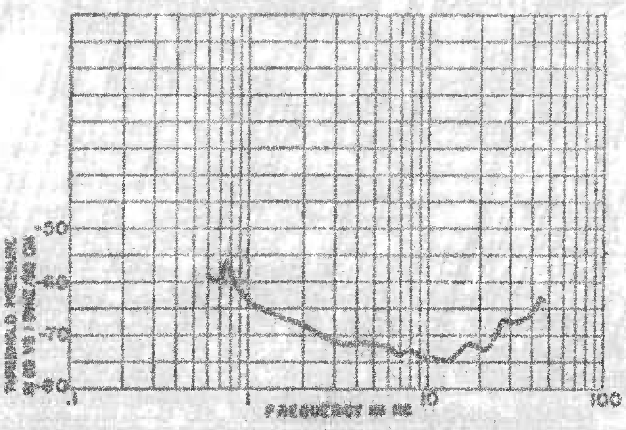

FIGURE 27. Calculated threshold, NL-130 hydrophone.

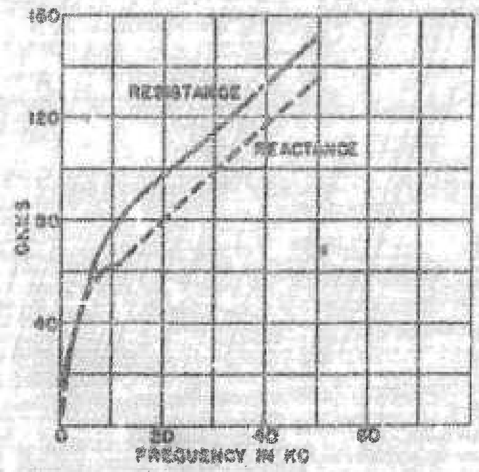

FIGURE 28. Impedance, NL-130 hydrophone.

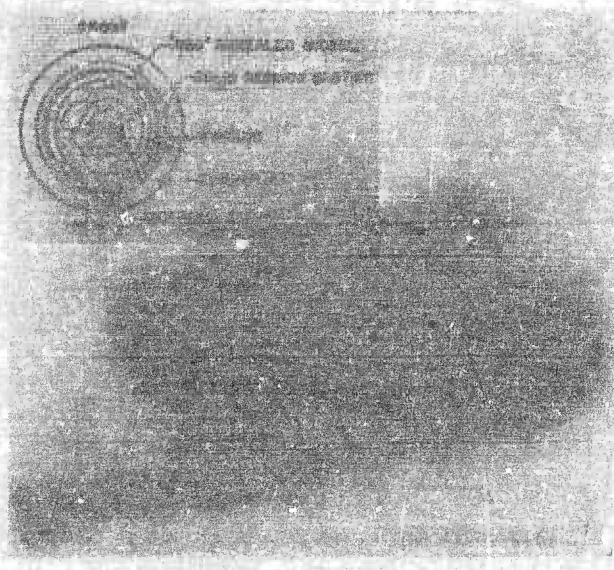

FIGURE 29. NL-130 hydrophone.

6.6.5 Toroidal Magnetostriction Hydrophone

Type: Magnetostriction.
Operating range: Audio frequencies.
References: BTL Technical Memorandum, April 29, 1942.[126]
NDRC Report No. C4-sr20-155, August 3, 1942.[127]
NDRC Report No. C4-sr20-214, July 1, 1942.[128]
NDRC Report No. C4-sr20-284, September 25, 1942.[129]
Use: For JP listening system.

Description: This design is a modification of the tubular magnetostriction hydrophone. The nickel tube is formed into a torus and the coil is wound around the inner circumference, hence no core is needed. The tube is mounted by means of four U-bolts on an annular steel backing plate. A sound-absorbent pad made of Corprene (rubber and cork) is cemented to the back of the steel plate to reduce rear response.

Another arrangement consists of two magnetostriction hydrophones suspended coaxially. Amplifiers are associated with each unit and an electric delay network is employed with one of them so that their outputs add if the sound is from one direction and cancel when the sound is from the opposite direction. As shown by the chart, this balance is effective only over a limited frequency range.

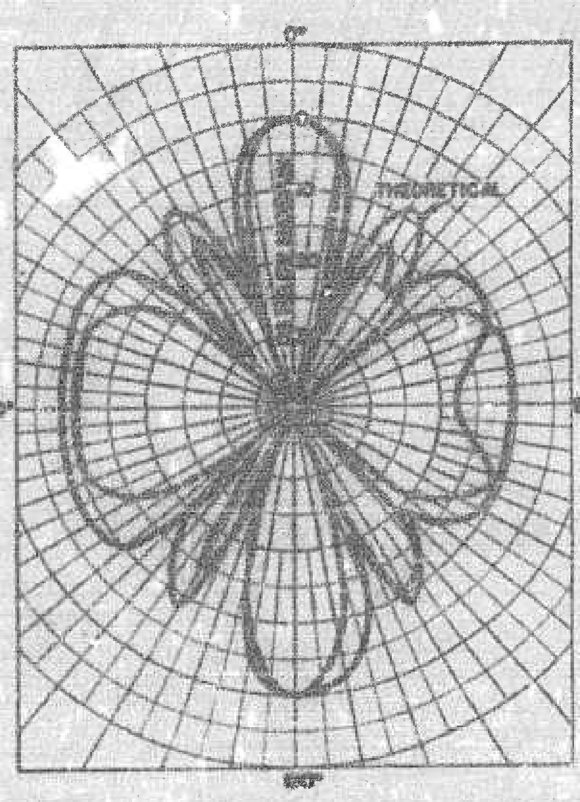

FIGURE 80. Directivity pattern, toroidal magnetostriction hydrophone at 5 kc.

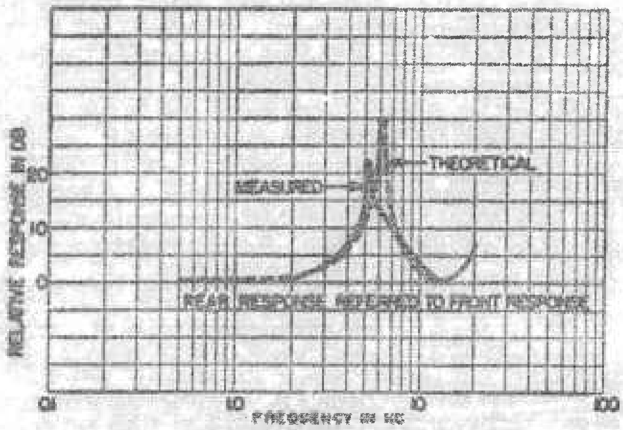

FIGURE 31. Difference between front and rear response, toroidal magnetostriction hydrophone.

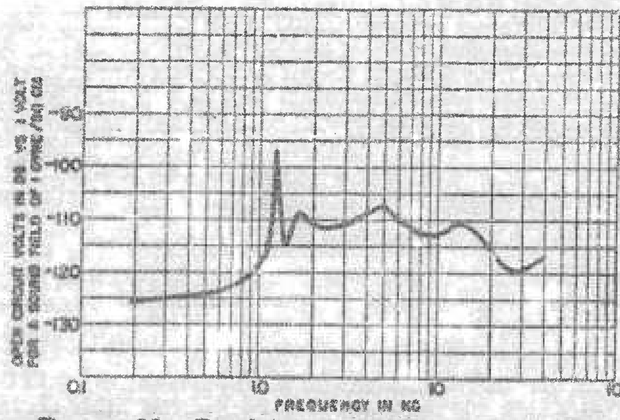

FIGURE 32. Receiving response, toroidal magnetostriction hydrophone.

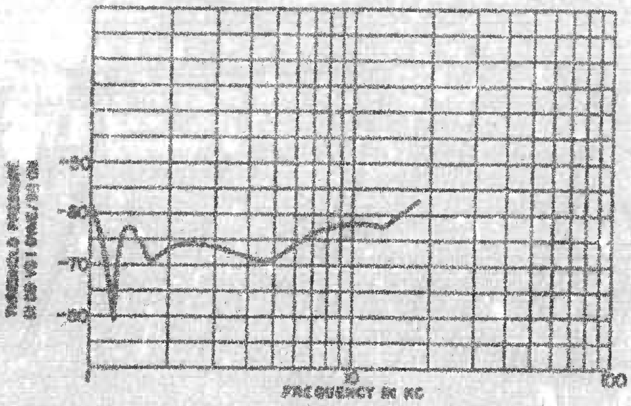

FIGURE 33. Calculated threshold, toroidal magnetostriction hydrophone.

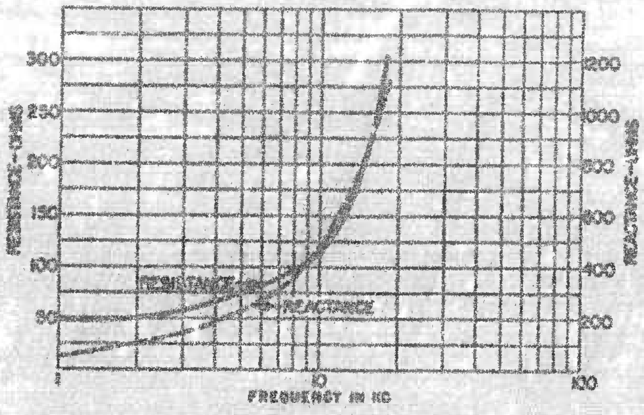

FIGURE 34. Impedance, toroidal magnetostriction hydrophone.

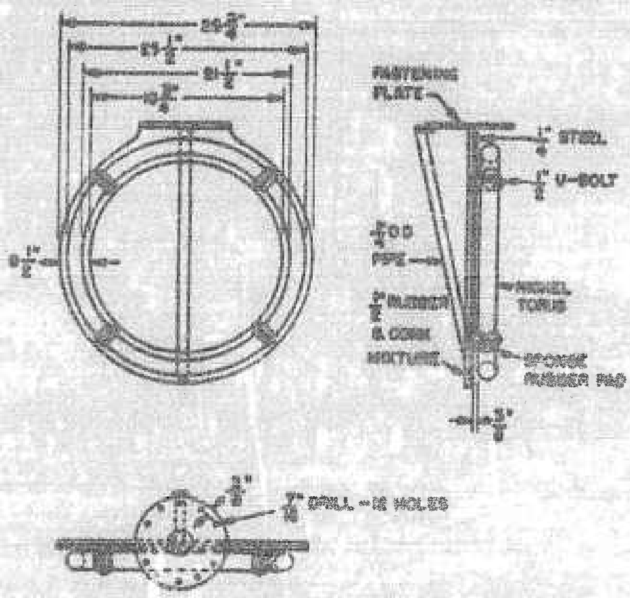

FIGURE 35. Toroidal magnetostriction hydrophone.

6.6.6 Tubular Magnetostriction Hydrophone

Type: Magnetostriction.
Operating range: Audio frequencies.
References: BTL Technical Memorandum, April 29, 1942.[123]
NDRC Report No. C4-sr20-196, August 15, 1942.[116]
NDRC Report No. C4-sr20-203, September 1, 1942.[126]
NDRC Report No. C4-sr20-095, March 17, 1942.[122]

Use: For harbor defense and overside listening from small surface patrol craft.

Description: The hydrophone consists of a cylindrical nickel tube, divided internally across the diameter by a laminated strip of Permalloy extending its length. The nickel tube is permanently magnetized so that no external polarizing batteries are needed. The hydrophone coil is wound lengthwise around the laminations. An impinging sound wave produces alternating stress in the nickel tube and a corresponding periodic variation in its permeability, thus modulating the flux and inducing an alternating voltage in the coil. Arrows indicate the direction of flux paths through the core and tube.

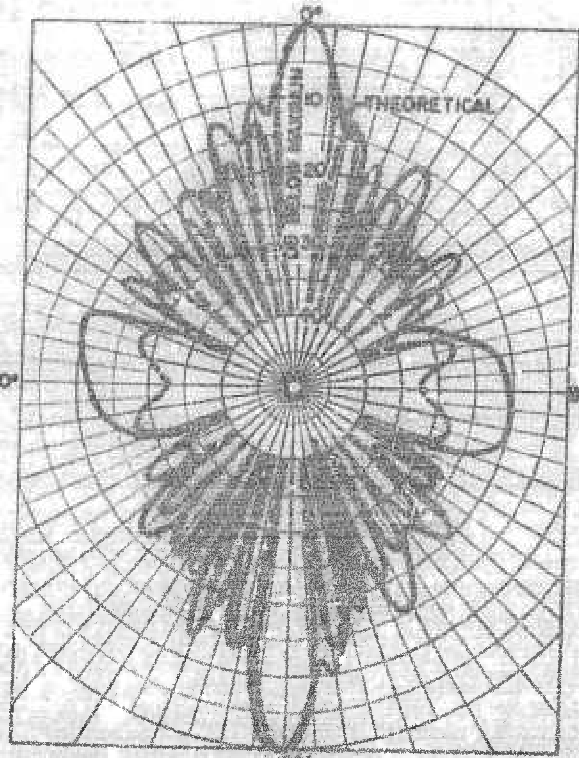

FIGURE 36. Directivity pattern, tubular magnetostriction hydrophone at 9.5 kc.

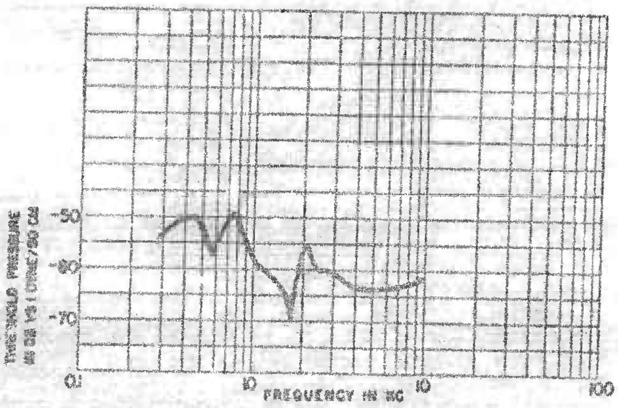

FIGURE 38. Calculated threshold, tubular magnetostriction hydrophone.

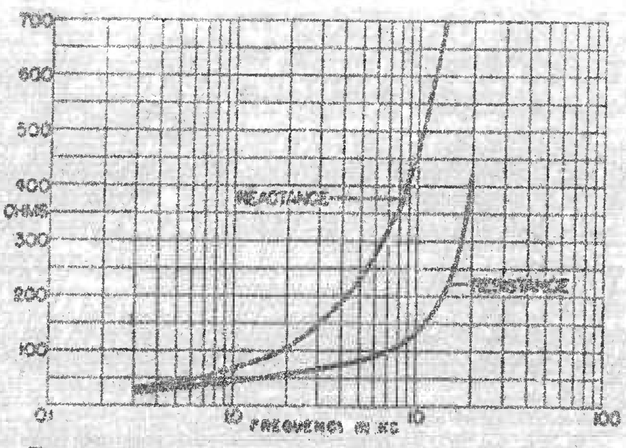

FIGURE 39. Impedance, tubular magnetostriction hydrophone.

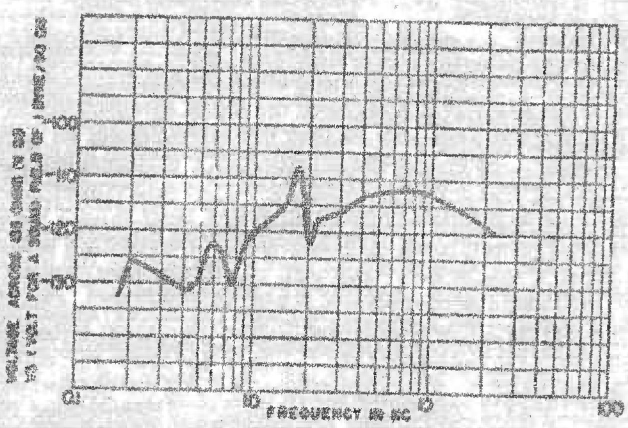

FIGURE 37. Receiving response, tubular magnetostriction hydrophone.

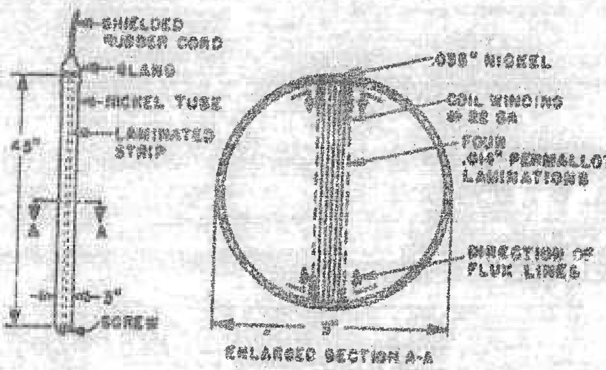

FIGURE 40. Tubular magnetostriction hydrophone.

6.6.7 HP Hydrophone

Type: Magnetostriction.

Designer: Underwater Sound Laboratory, Massachusetts Institute of Technology.

Reference: NDRC Report No. C4-sr20-182, July 15, 1942.[120]

Use: Working standard.

Description: The HP hydrophone differs in only two significant features from HK hydrophones. (1) In HP, the crystal pack is mounted directly in a square hole in the solid brass hydrophone head, with thin sheets of insulator where necessary. In HK, the crystals are first mounted in a bakelite holder which is then fitted into a circular hole in the hydrophone head. (2) The preamplifier of the HP hydrophone contains a calibrating resistance, which is not installed on the HK preamplifier. Otherwise, the characteristics of the HP are very similar to those of the HK hydrophones (see Section 1.4.19).

The HP is used with the PAR sound level indicator which was also designed at MIT. This apparatus can measure sounds of frequency from 0.2 to 10 kc within a few decibels and from 10 to 50 kc with greater error. Pressure levels can be measured in the range from 30 to 75 db above one dyne per sq cm and the equipment can work into any recorder with an input impedance greater than 10,000 ohms.

6.6.2 HU Hydrophone

Type: Magnetostriction.

Designer: Underwater Sound Laboratory, Massachusetts Institute of Technology.

References: NDRC Report No. 6.1-sr20-619, May 6, 1943.[19]
NDRC Report No. 6.1-sr20-879, June 19, 1943.[21]

Use: Measurements in high-intensity sound fields.

Description: The HU is a low-sensitivity hydrophone for sound pressure measurements in high-intensity sound fields of frequencies from 20 to 1,000 c. The magnetostrictive element is a nickel bar which is magnetized by momentary application of a 90-v polarizing potential. The housing above the bar contains an equalizer circuit designed to operate into a 5,000-ohm load.

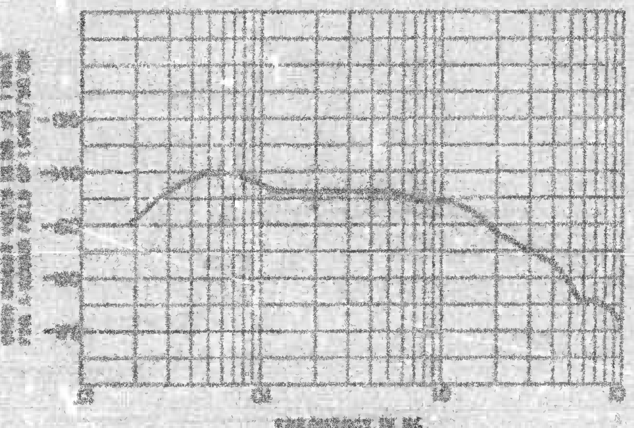

FIGURE 41. Receiving response, HU hydrophone.

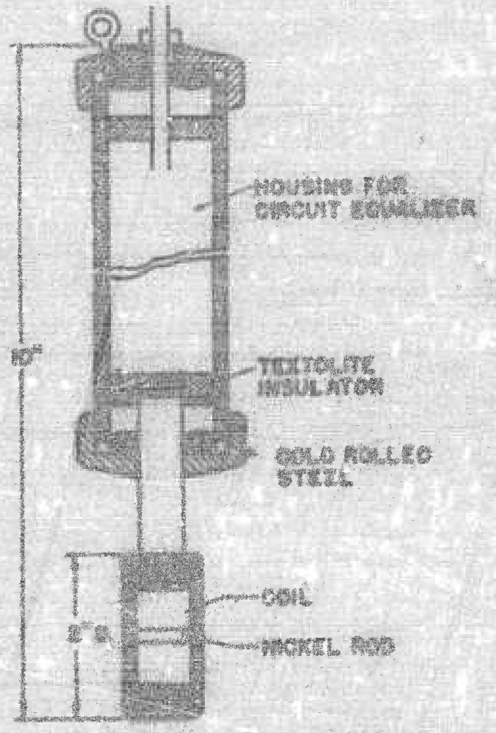

FIGURE 42. HU hydrophone.

6.4.9 XPA Projector

Type: X-Cut Rochelle Salt Crystal.

Operating range: 2 to 50 kc.

Designer: Underwater Sound Laboratory, Massachusetts Institute of Technology.

Reference: NDRC Report No. 6.1-sr1130-1631, June 29, 1944.[146]

Description: The crystal block contains 144 X-cut Rochelle salt crystals connected in parallel. A ⅛-in. rubber diaphragm is cemented directly to the crystal face. The crystal bank is mounted in a brass frame and the entire assembly has been dipped in latex rubber. The projector should be driven with a constant current input from a 250-ohm to a 500-ohm source, depending upon the frequency range.

Overall dimensions: 13½ by 3⅛ by ½ in.

Impedance in ohms.

Frequency (kc)	Resistance	Reactance
0.5	122.2	$-j2345$
1.0	69.4	$-j1190$
2.0	29.9	$-j613$
5.0	24.2	$-j227$
10.0	44.4	$-j124.7$
20.0	19.5	$-j41.6$
50.0	93.6	$-j6.96$
100.0	12.5	$-j70.5$

Efficiency: —12.5 db at 6 kc.

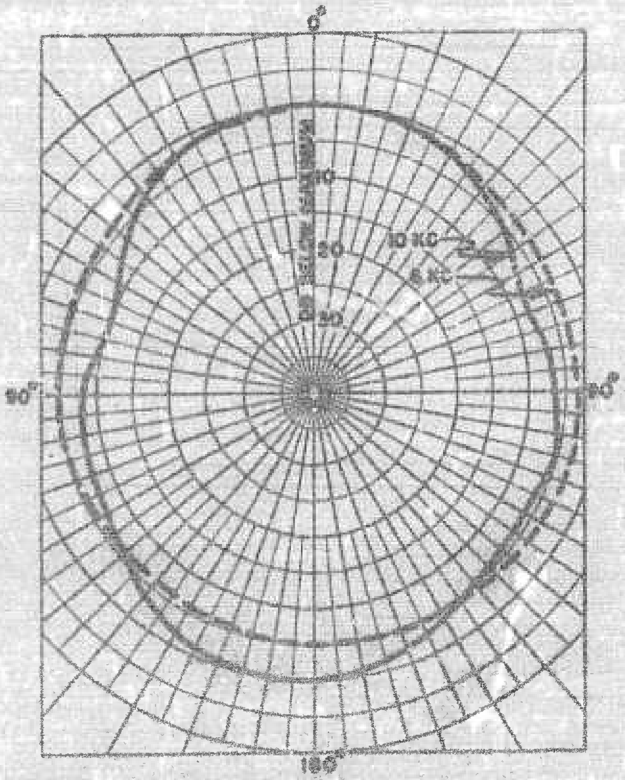

FIGURE 43. Directivity patterns, XPA projector in a plane perpendicular to axis at 6 kc and 10 kc.

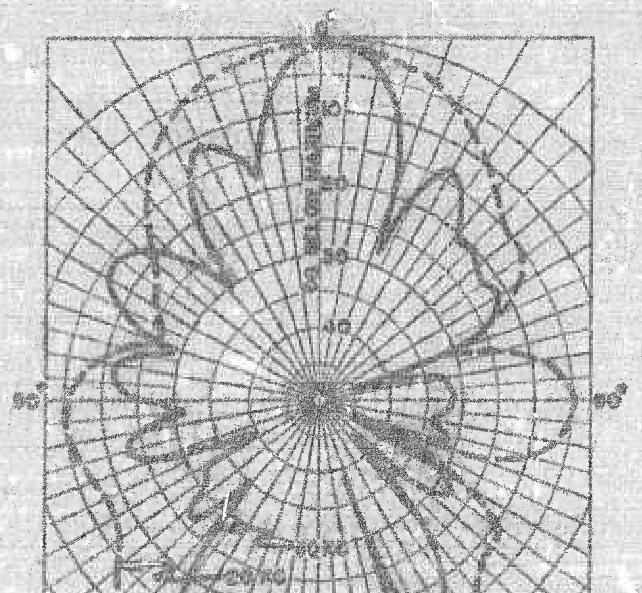

FIGURE 44. Directivity patterns, XPA projector in a plane perpendicular to axis at 20 kc and 60 kc.

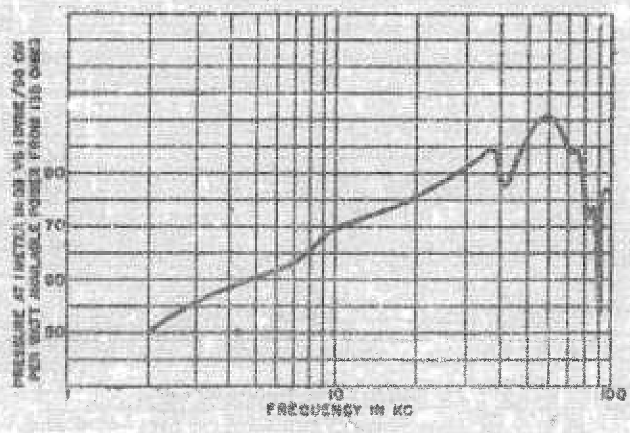

FIGURE 45. Transmitting response, XPA projector.

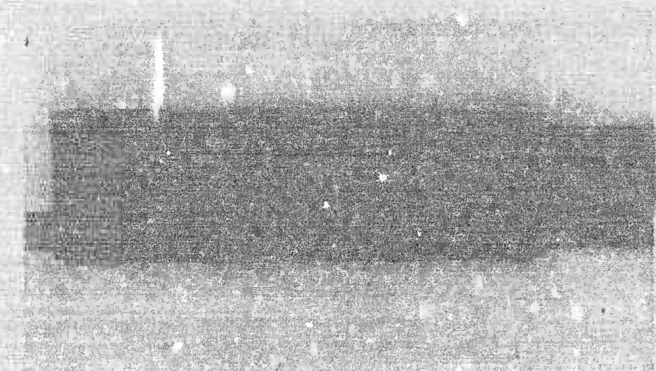

FIGURE 46. XPA projector.

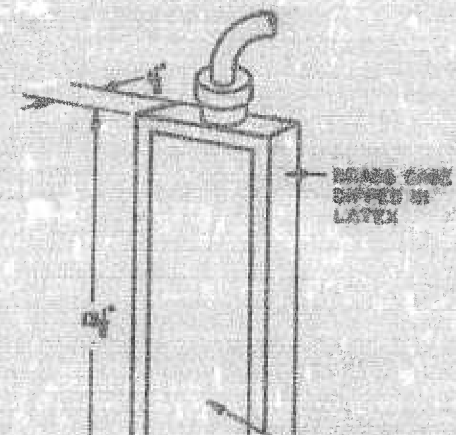

FIGURE 47. Dimensional drawing, XPA projector.

6.6.19 CJJ-78256 Serial 20 Sound Head

Type: Z-Cut ADP Crystal.

Designer: University of California, Division of War Research.

Reference: Calibrated by UCDWR. Letter from C. J. Burbank to R. S. Shankland, August 27, 1945.

Description: The CJJ sound head is a cylinder 28 in. long and 14½ in. in diameter. It contains a transmitting projector and a receiving hydrophone, each acoustically and electrically isolated and enclosed in a steel shell having a 2-in. thick ρc rubber window as its face. The projector is nearer the mounting studs. The free space within the cylinder is filled with electrical grade castor oil.

The projector element is composed of 12 bars, arranged into a 90° sector of a cylinder; each bar has 28 Z-cut ADP elements, arranged in groups of four and all connected in parallel. The individual elements are 0.80 in. long, 0.80 in. wide, and 0.25 in. thick. The bars, each 8½ in. long, ¾ in. wide, and ¾ in. thick, have a layer of porcelain approximately 0.06 in. thick bonded to the crystal-mounting surface, which serves to insulate the crystals electrically from the metal.

The receiver element is lobe-suppressed, with an inner section 5 in. in diameter and an outer under-driven section 9.5 in. in diameter. The 408 ADP crystals, the same size as those in the projector, are arranged in the section in groups of three, all connected in parallel, while, in the outer section, the individual crystals in each group of three are connected in series and the groups in parallel. The individual crystals in the two sections are therefore connected to give a voltage ratio of three to one. The layer of porcelain between the crystals and the ¾-in. thick backing plate is approximately 0.04 in. thick.

Each of the units has balanced series tuning coils chosen to operate with it. Foam rubber is used in the following places: (1) the back of the receiver backing plate, (2) the edges of the transmitter crystals, except the radiating edge, (3) between the groups of crystals in the receiver array, (4) on the opposite faces of the partition between the transmitter cavity and the receiver cavity, (5) behind the bars of the transmitter, and (6) on an interior baffle behind the transmitter unit.

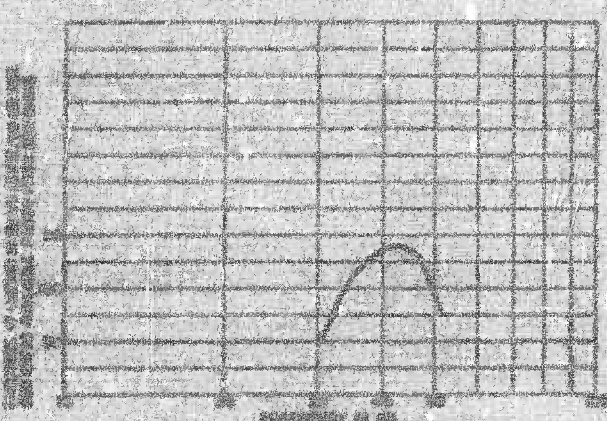

FIGURE 48. Transmitting response, CJJ-78256 serial 20 sound head.

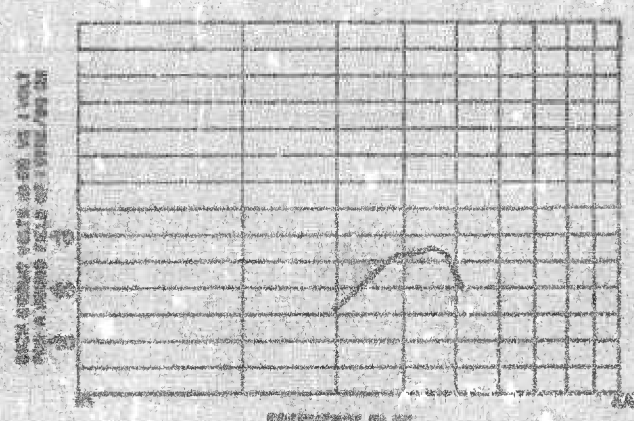

FIGURE 49. Receiving response, CJJ-78256 Serial 20 sound head.

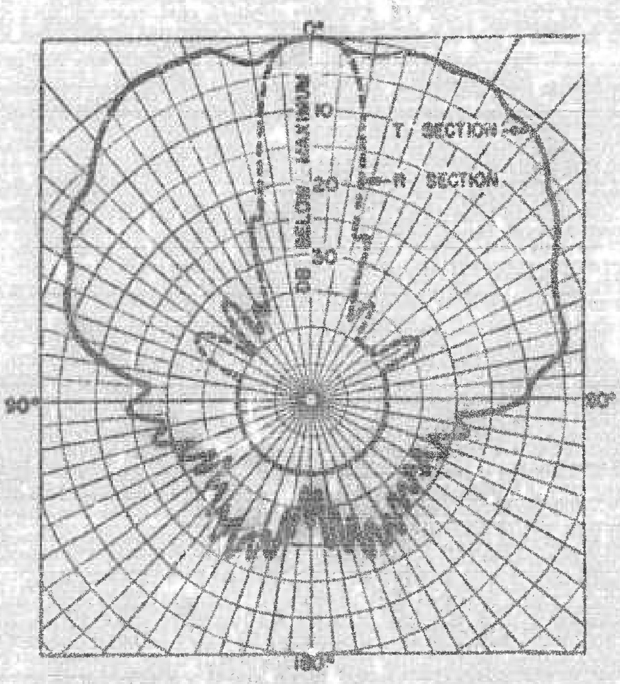

FIGURE 50. Directivity pattern, CJJ-78256 serial 20 sound head at 42 kc.

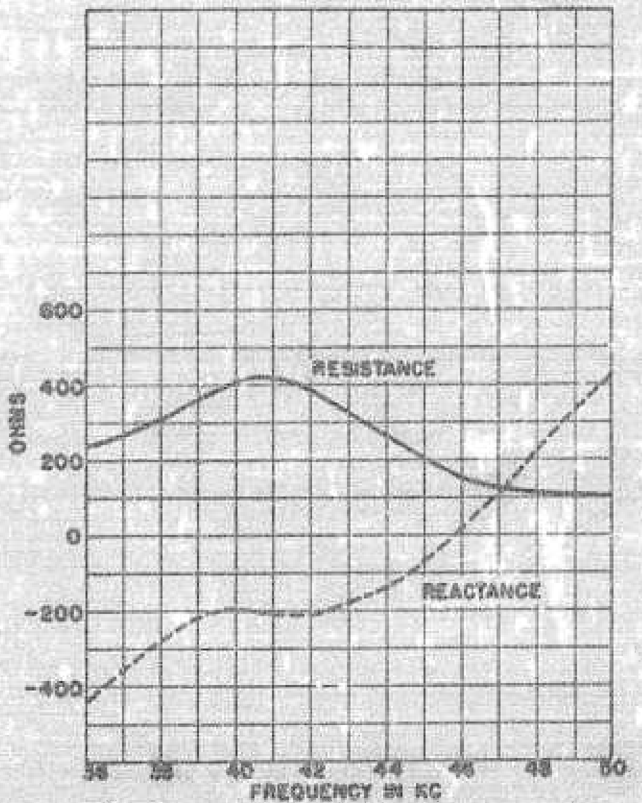

FIGURE 52. Impedance, transmitter section of CJJ-78256 serial 20 sound head.

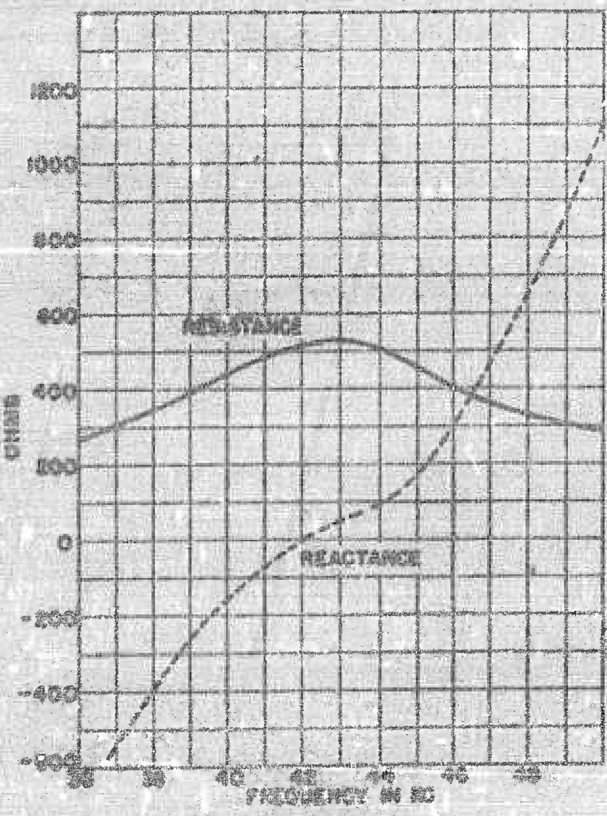

FIGURE 51. Impedance, hydrophone section of CJJ-78256 serial 20 sound head.

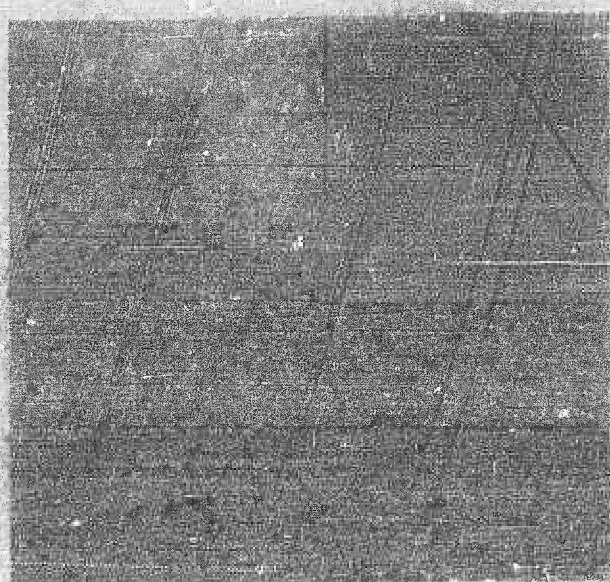

FIGURE 53. Exploded view, CJJ-78256 serial 20 sound head.

6.8.11 CY4 Sample 3A Transducer

Type: Y-Cut Rochelle Salt Crystal.

Designer: University of California, Division of War Research.

Reference: Calibrated by UCDWR. Letter from C. J. Burbank to R. S. Shankland, August 27, 1945.

Description: The CY4 Sample 3A is a cylindrical device consisting of a crystal unit housed in a standard 1-pt olive can. The crystal assembly is composed of 20 Y-cut Rochelle salt crystals, each 1½x1x¼ in., in a straight stack, all connected in parallel. Undesired radiation from the sides of the stack is suppressed by strips of Corprene; and disks of neoprene, separated from the ends of the crystal assembly by Lucite spacers, serve to center the unit in the can. The space within the can not otherwise occupied is filled with electrical grade castor oil.

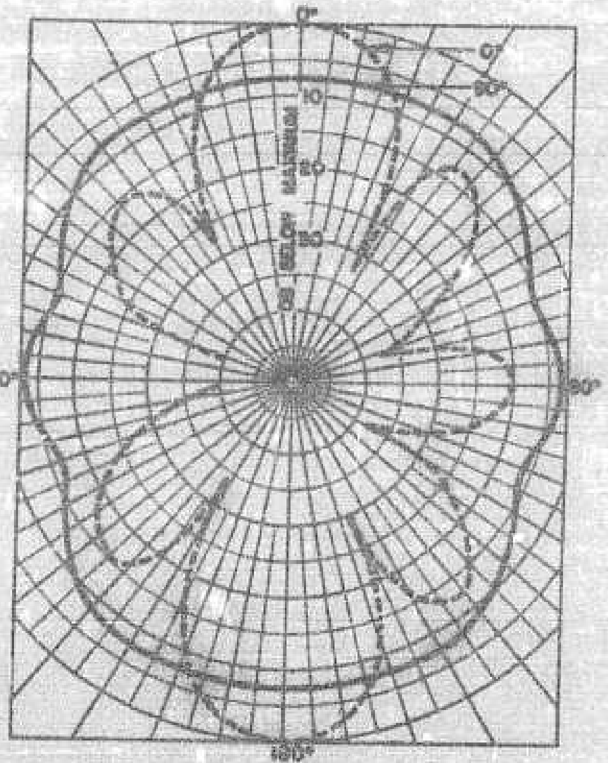

Figure 54. Directivity pattern, CY4 sample 3A transducer at 23 kc.

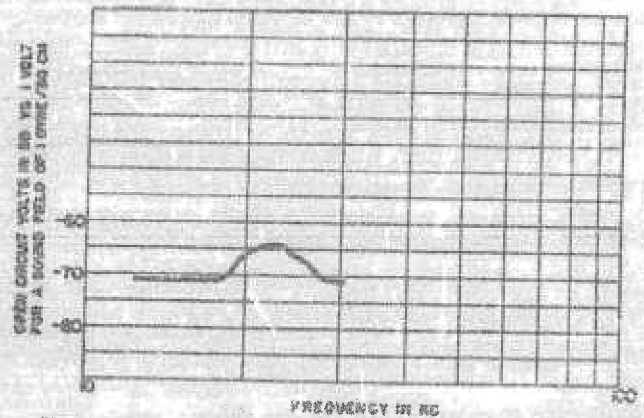

Figure 56. Receiving response, CY4 sample 3A transducer.

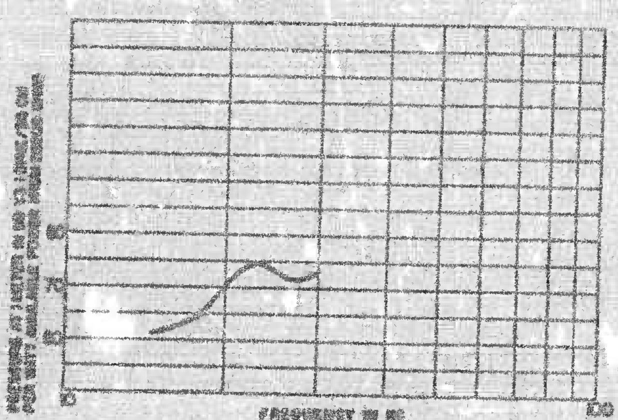

Figure 55. Transmitting response, CY4 sample 3A transducer.

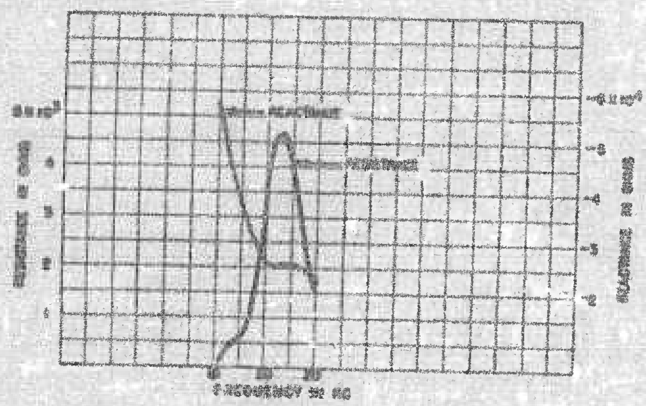

Figure 57. Impedance, CY4 sample 3A transducer.

6.6.12 EP2Z Transducer

Type: Z-Cut ADP Crystal.

Designer: University of California, Division of War Research.

Reference: Calibrated by UCDWR. Letter from C. J. Burbank to R. S. Shankland, August 27, 1945.

Description: This is a "flashlight" type unit, housed in a cylindrical aluminum case $3^{15}/_{16}$ in. in diameter. The transducer element is a $2\frac{1}{2}$-in. diameter circular array of 98 Z-cut ADP crystals, each 0.470x0.088x0.50 in., all connected in parallel, Cycle-Welded to a 40-shore neoprene diaphragm $\frac{1}{8}$ in. thick which acts as a sound window. The unit is air-filled.

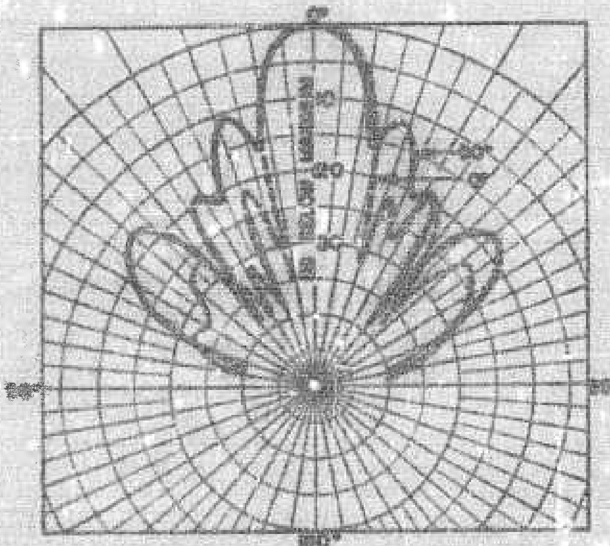

FIGURE 58. Directivity pattern, EP2Z-6 transducer at 110 kc.

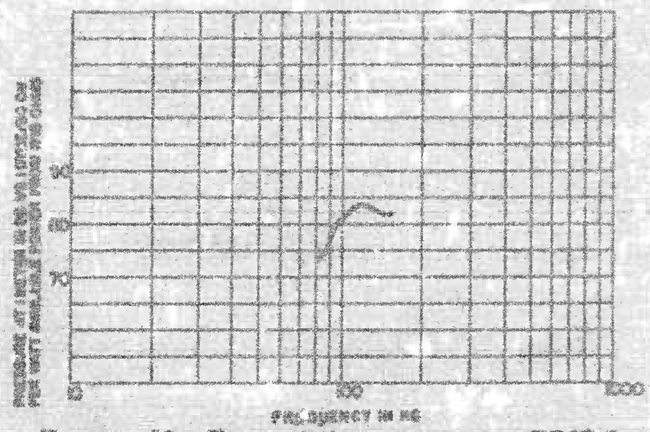

FIGURE 59. Transmitting response, EP2Z-6 transducer.

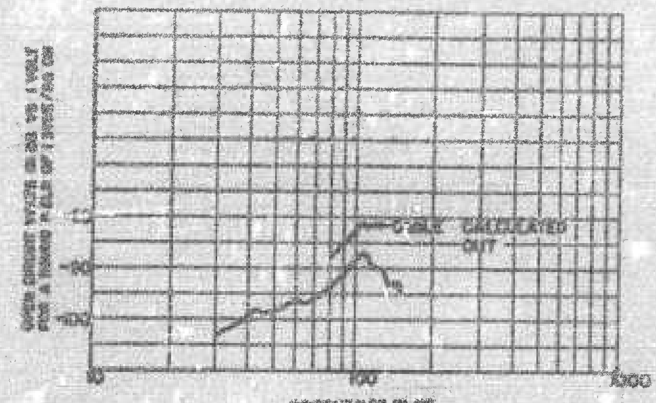

FIGURE 60. Receiving response, EP2Z-6 transducer.

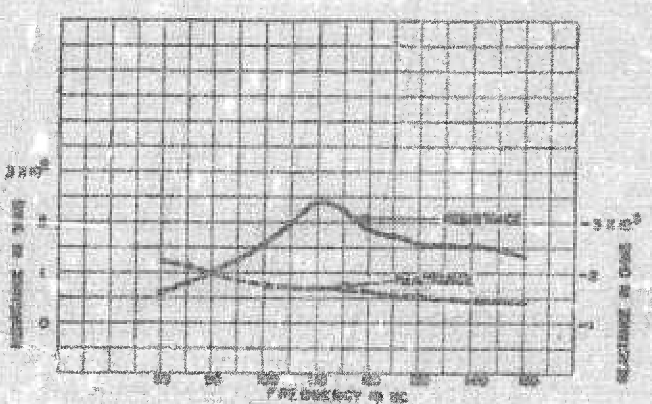

FIGURE 61. Impedance, EP2Z-6 transducer.

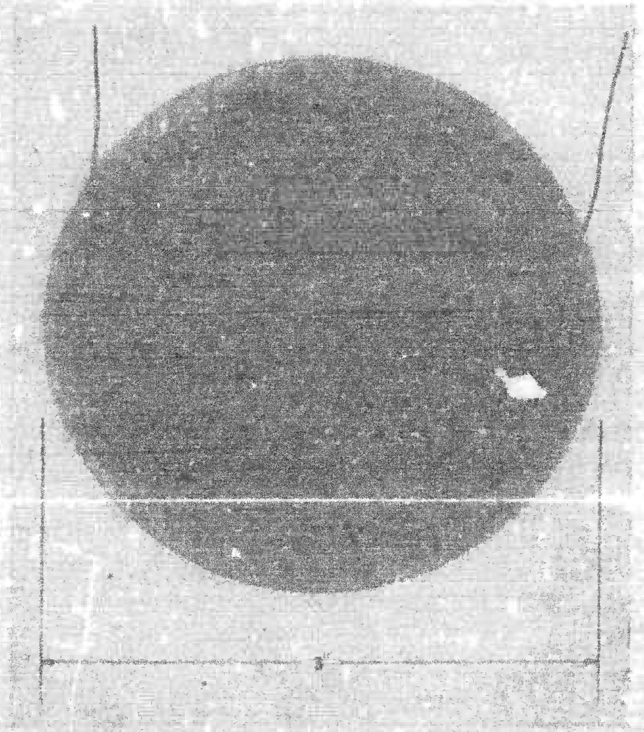

FIGURE 62. Crystal assembly, EP2Z-6 transducer.

FIGURE 63. Housing of EP2Z-6 transducer.

6.6.13 FE2Z Transducer

Type: Z-Cut ADP Crystal.

Designer: University of California, Division of War Research.

Reference: Calibrated by UCDWR. Letter from C. J. Burbank to R. S. Shankland, August 27, 1945.

Description: This unit consists of a roughly diamond-shaped array of 98 Z-cut ADP crystals, each 0.574x0.50x0.25 in., all connected in parallel, Cycle-Welded to the ⅛-in. neoprene window of a cast Meehanite case about 12 in. long, 5 in. wide, and 6 in. deep, in whose top compartment the crystal unit is backed by foam rubber. (Figure 68 shows a shallower aluminum case.) The unit is gas-filled.

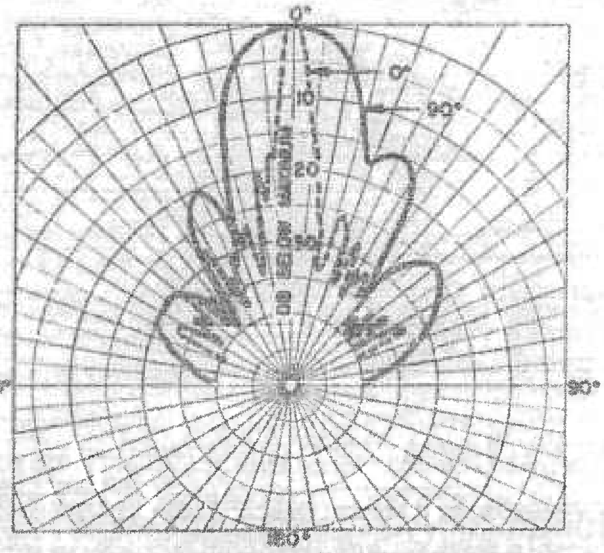

FIGURE 64. Directivity pattern, FE2Z-1 transducer at 90 kc.

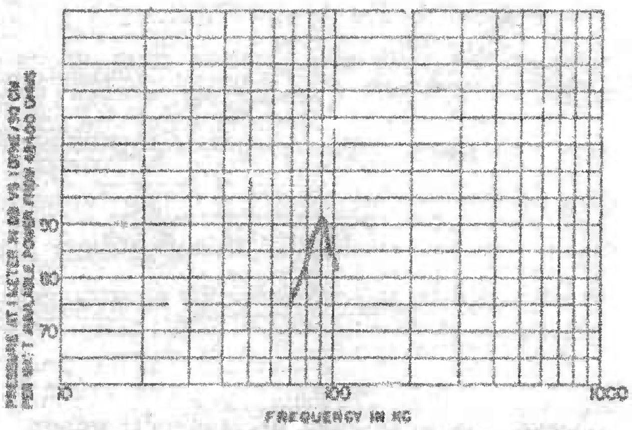

FIGURE 65. Transmitting response, FE2Z-1 transducer.

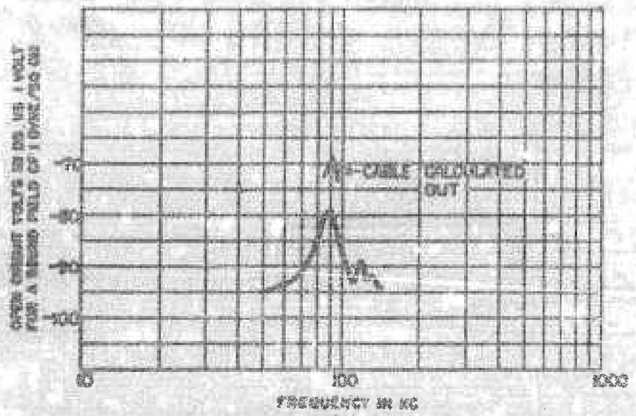

FIGURE 66. Receiving response, FE2Z-1 transducer.

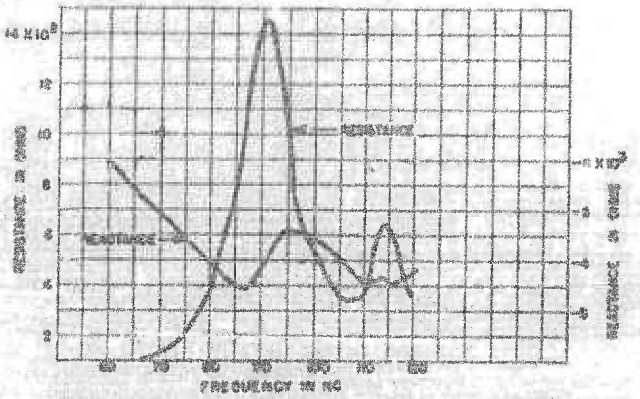

FIGURE 67. Impedance, FE2Z-1 transducer.

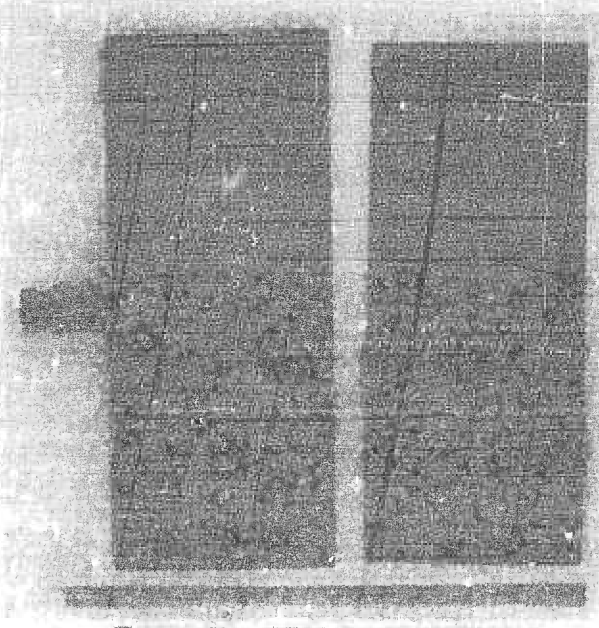

FIGURE 68. FE2Z-1 transducer.

4.6.14 GA2 Transducer

Type: 45° X-Cut Rochelle Salt Crystal.

Designer: University of California, Division of War Research.

Reference: NDRC Report No. 6.1-sr20-873, May 18, 1943.[138]

Also calibrated by UCDWR. Letter from C. J. Burbank to R. S. Shankland, August 27, 1945.

Description: The active face of the transducer is approximately 8 in. square. It consists of 8 rows of 26 crystals each, covered with a rubber diaphragm. The space between the crystals and diaphragm is oil-filled. The case is cast iron, with dimensions as shown in Figure 74.

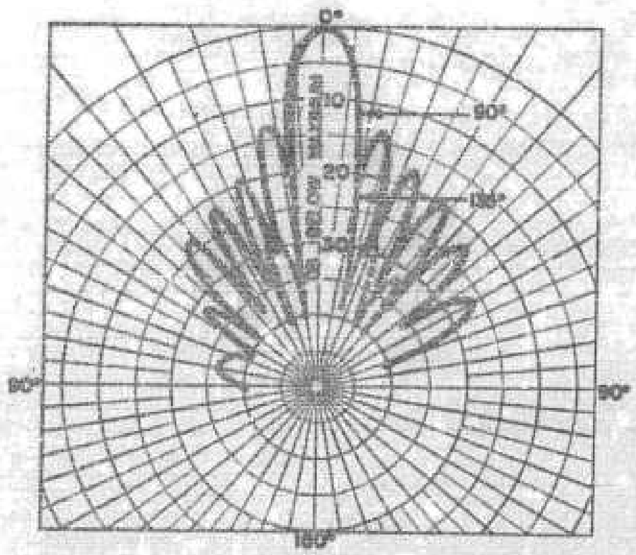

FIGURE 69. Directivity pattern, GA2 transducer at 50 kc.

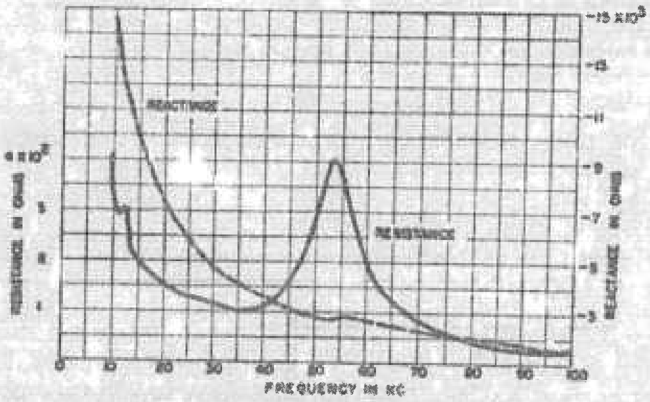

FIGURE 72. Impedance, GA2 transducer.

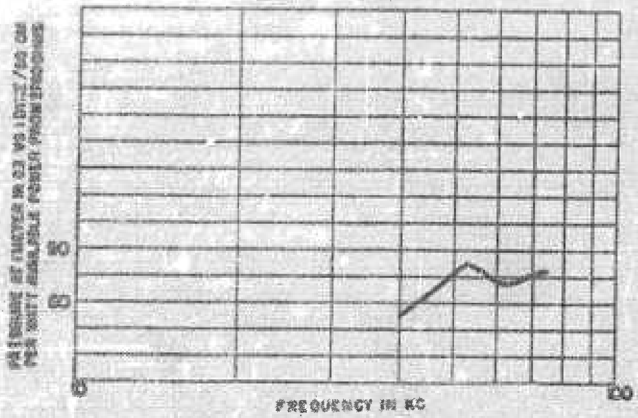

FIGURE 70. Transmitting response, GA2 transducer.

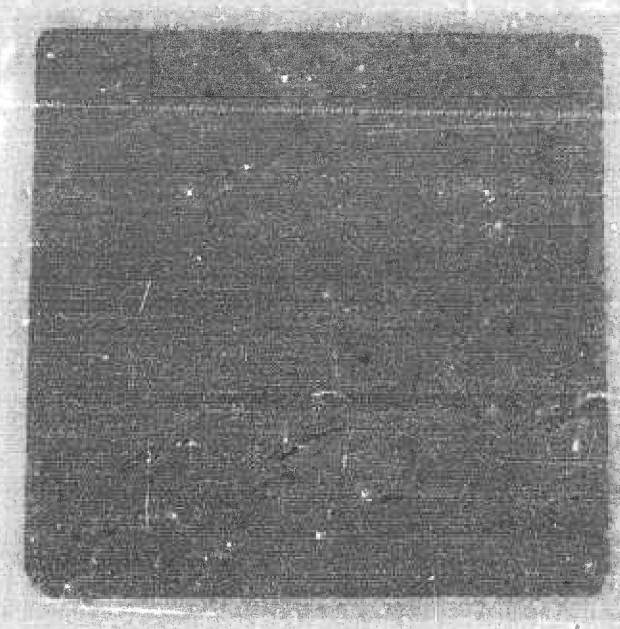

FIGURE 73. Crystal assembly, GA2 transducer.

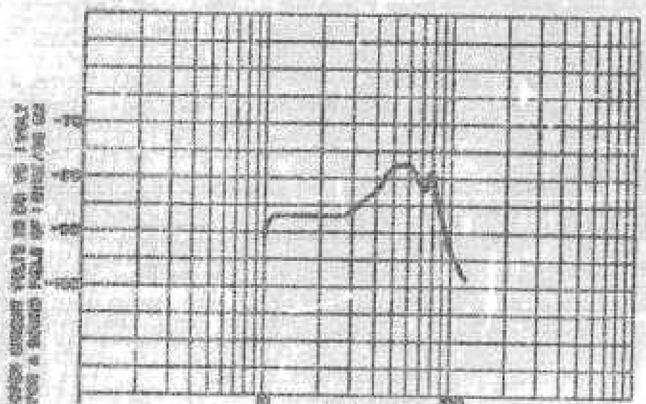

FIGURE 71. Receiving response, GA2 transducer.

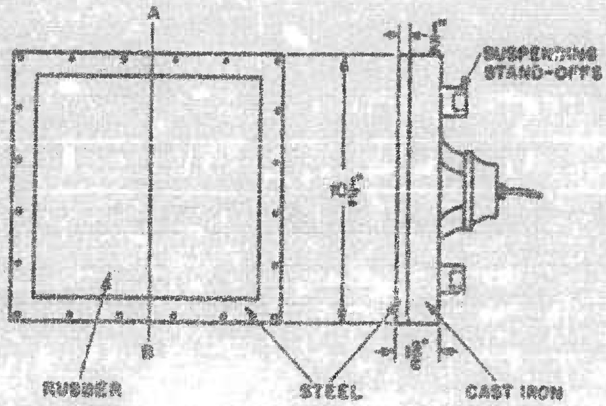

FIGURE 74. Dimensional drawing, GA2 transducer.

6.6.12 GD16-17 Transducer

Type: 45° Y-Cut Rochelle Salt Crystal.

Designer: University of California, Division of War Research.

Reference: Calibrated by UCDWR. Letter from C. J. Burbank to R. S. Shankland, August 27, 1945.

Description: The GD16-17 No. 1868 consists of 168 45° Y-cut Rochelle salt crystals, each ⅜x1x½ in., connected in parallel, cemented in close array to the porcelain-enameled surface of a ½-in. steel backing plate, forming an active face approximately 4x4½ in. A strip of ¼-in. thick canvas bakelite is cemented to the backing plate on either side of the crystal assembly. The transducer element is nested in Corprene in a cast Meehanite case approximately 6 in. square and 3 in. deep, with a neoprene sound window bonded into the Meehanite. All the space within the case not otherwise occupied is filled with electrical grade castor oil.

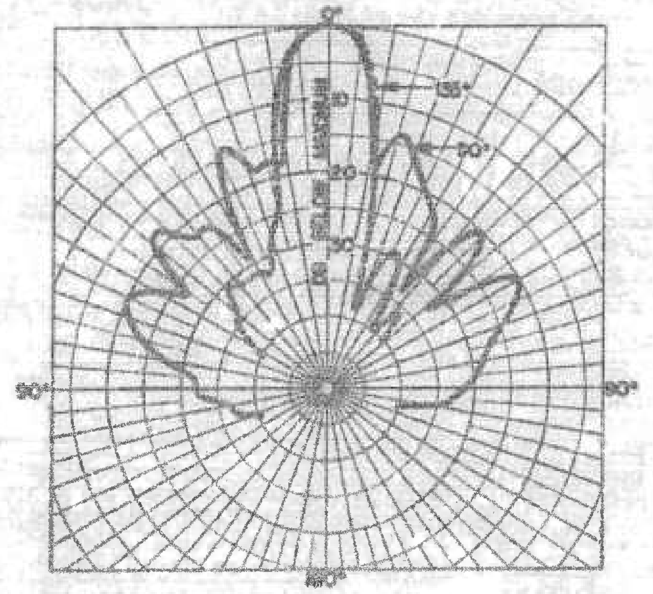

FIGURE 75. Directivity pattern, GD16-17 transducer at 80 kc.

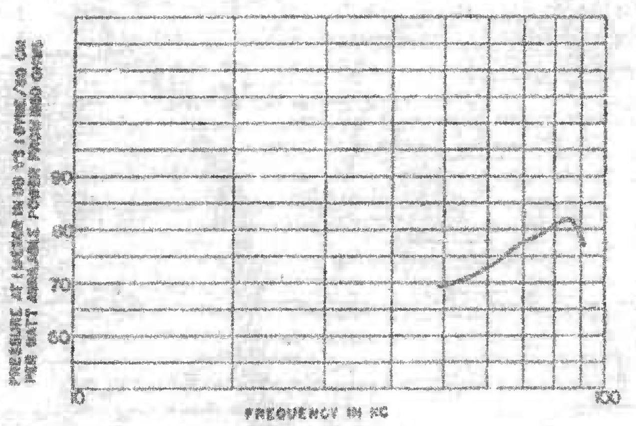

FIGURE 76. Transmitting response, GD16-17 transducer.

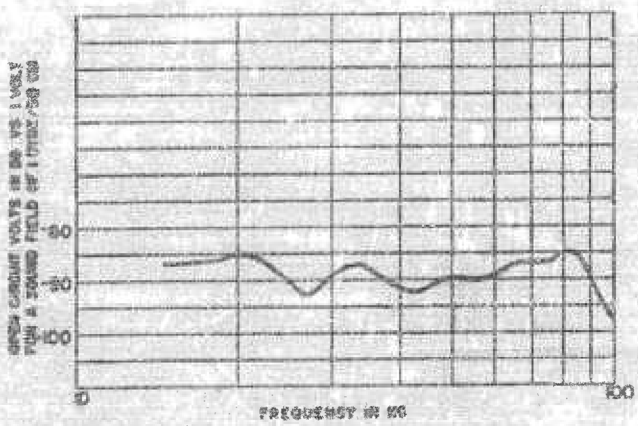

FIGURE 77. Receiving response, GD16-17 transducer.

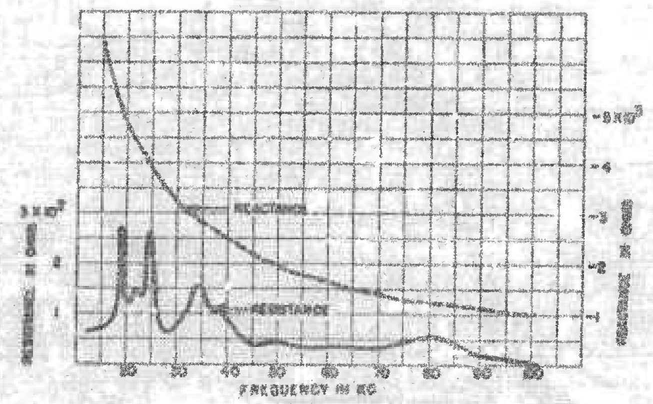

FIGURE 78. Impedance, GD16-17 transducer.

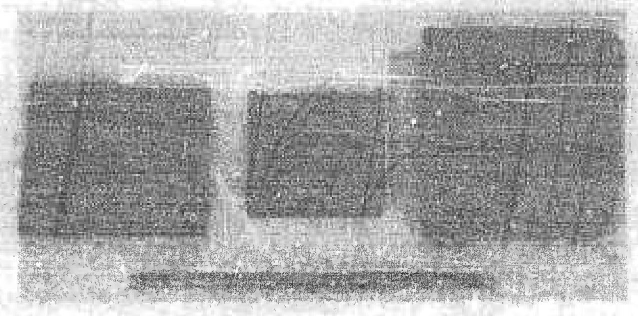

FIGURE 79. GD16-17 transducer.

6.6.16 GD34Z-1 Transducer

Type: Z-Cut ADP Crystal.

Designer: University of California, Division of War Research.

Reference: Calibrated by UCDWR. Letter from C. J. Burbank to R. S. Shankland, August 27, 1945.

Description: This transducer, air-filled, consists of a transducer element of 72 Z-cut ADP crystals, each 1¼x½x¼ in., all connected in parallel, cemented together in pairs, six pairs per row, and Cycle-Welded to a ρc rubber sound window 1¾ in. thick. Imbedded in the ρc window between rows of crystals are five steel alloy bars 1 in. high and ⅛ in. wide, with ¾ in. space center-to-center of the bars. The total array is approximately 4¾x4½ in., and is fitted into a square cast Mechanite case about 3 in. deep.

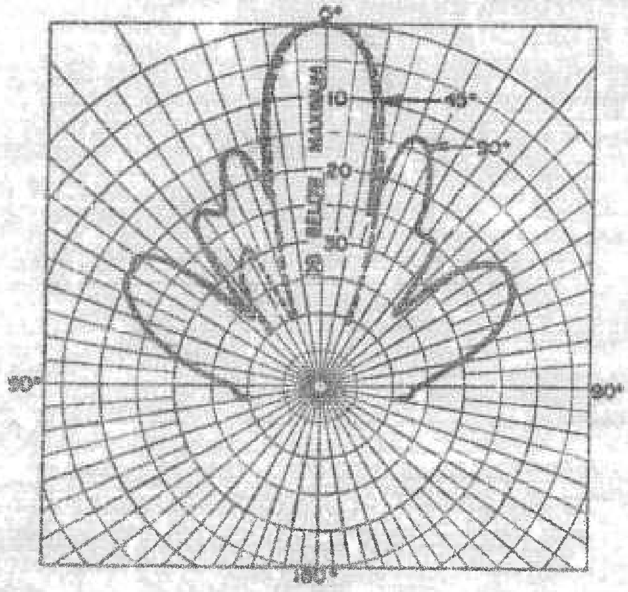

FIGURE 80. Directivity pattern, GD34Z-1 transducer at 49 kc.

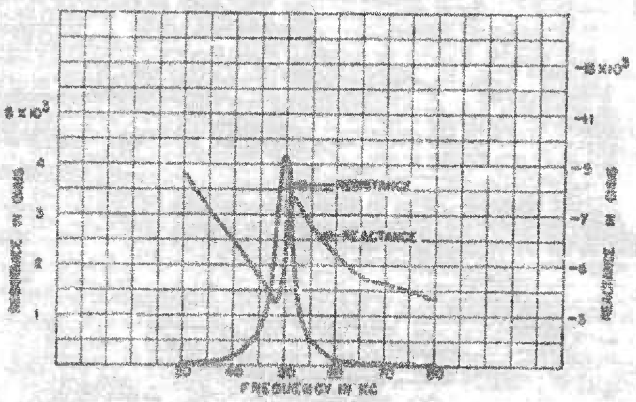

FIGURE 83. Impedance, GD34Z-1 transducer.

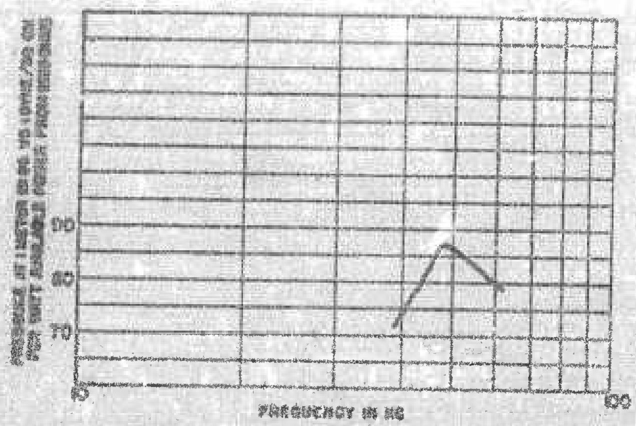

FIGURE 81. Transmitting response, GD34Z-1 transducer.

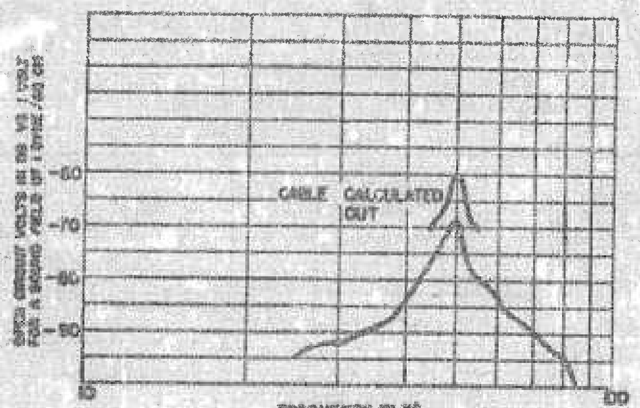

FIGURE 82. Receiving response, GD34Z-1 transducer.

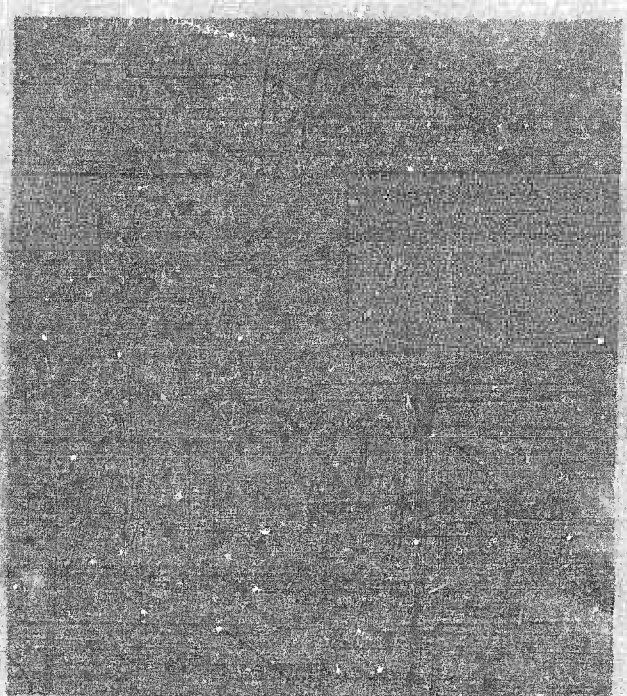

FIGURE 84. Rear view, GD34Z-1 transducer crystal assembly.

6.7 TOURMALINE GAUGES

Tourmaline gauges have been used in oil exploration work to measure the strength and time of arrival of explosion waves and their reflections in the ground.

These designs have been adapted to the measurement of underwater explosive sounds. The USRL has calibrated such devices for the David Taylor Model Basin, the Woods Hole Oceanographic Institution [WHOI], and the MIT Underwater Sound Laboratory. Most of the instruments submitted were manufactured by the Stanolind Oil and Gas Company of Tulsa, Oklahoma.

The measurement of explosive sounds imposes a number of special requirements on a hydrophone.[144] Some of these requirements may be summarized as follows.

1. The mechanical strength of the device must be sufficient to withstand the shock.

2. The device must be capable of carrying the highest peak sound pressure without overloading.[a]

3. The response must be uniform over a wide frequency range.[132]

For satisfactory measurements of explosive sounds, uniform response is required from frequencies below 100 c to the megacycle region. In the present state of instrument design this can only be approximated. The usual design uses a very small crystal having a natural frequency at, or possibly above, the maximum frequency of interest. Tourmaline generally is preferred because it possesses a volume piezoelectric effect which the other generally available crystals do not have. As a consequence, diffraction affects the response to a lesser degree because flexure set up by the diffracted wave and the pressure at the edges do not affect tourmaline.[132] In addition, the face of the hydrophone is made small to minimize diffraction effects, and its thickness is made small to obtain high-frequency resonance. When this is done, the pressure of the shock wave does not change appreciably in the time required to traverse the crystal. This design has the further advantage that below the natural frequency phase shift is linear with frequency, which is necessary if oscillograms of the sound waves are to be taken.[132]

It will be realized that such a hydrophone is very inefficient and has a very high impedance. There are two methods for taking care of this situation. One consists in associating a preamplifier with the crystal as closely as possible, keeping the length of leads between the two a minimum. The preamplifier then is located underwater at the point where the wave is measured; hence, it must be designed to withstand the full power of the explosion. In the other method, which has been used by WHOI, instead of the open-circuit voltage, the electric charge on the crystal is measured. This measurement[b] is independent of the length of cable intervening between the crystal and the preamplifier. Thus it is possible to move the latter to a safe distance, out of the water entirely.

To measure small explosion charges of the order of magnitude of a No. 6 blasting cap, the USRL has used the XMX hydrophone described in Section 1.4.21. Heavy explosions undoubtedly would shatter the Rochelle salt crystal used for the active element in this instrument. The only available piezoelectric materials that can withstand such extreme pressures are quartz and tourmaline.

[a] See discussion in STR Division 6, Volume 10, Chapter 5.

[b] See STR Division 6, Volume 10, Chapter 4.

6.7.2 TMB Tourmaline Gauge

Type: X-Cut Tourmaline Crystal.

Designer: David Taylor Model Basin.

Reference: USRL calibration letter to Rear Admiral H. S. Howard dated October 19, 1944.

Use: For measuring high-pressure underwater sound.

Description: This unit uses a small tourmaline crystal, or crystals, enclosed in a soft rubber cover with a 2-in. long neck. One or more insulated leads are carried inside a ⅛-in. copper tube which is grounded through the water, thus forming a shield. The design is similar to that of the Stanolind Oil and Gas Company tourmaline gauges. The useful frequency range extends to about 1 mc.

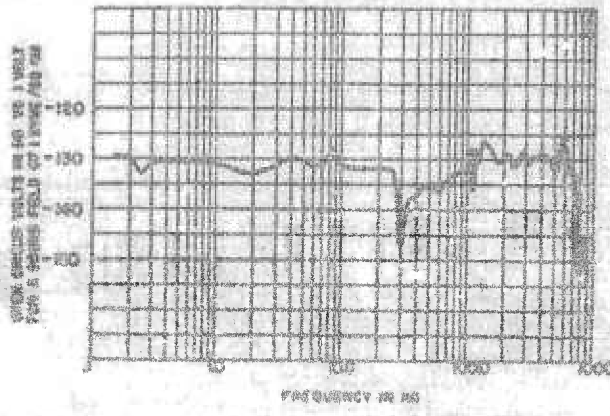

FIGURE 85. Receiving response, TMB tourmaline gauge.

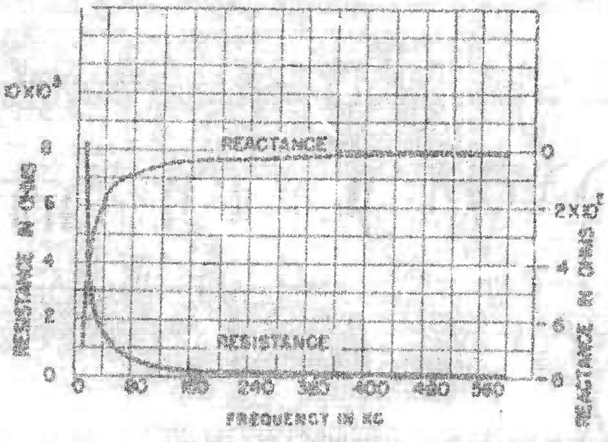

FIGURE 87. Impedance, TMB tourmaline gauge.

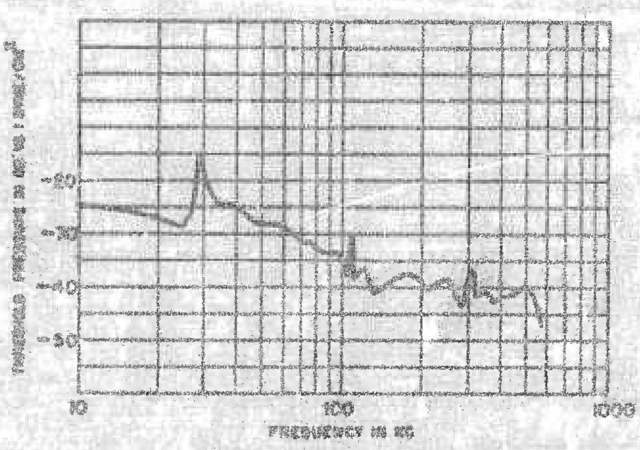

FIGURE 86. Calculated threshold, TMB tourmaline gauge.

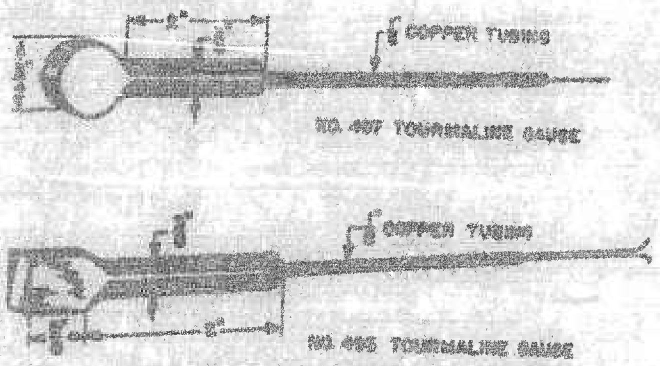

FIGURE 88. TMB tourmaline gauge.

6.7.2 TMB-T1 Hydrophone

Type: X-Cut Tourmaline Crystal.

Designer: David Taylor Model Basin.

Reference: USRL calibration letter to Rear Admiral H. S. Howard dated October 19, 1944.

Use: To measure high-pressure underwater sounds.

Description: The TMB-T1 hydrophone uses a small tourmaline disk with a molded rubber cover. A $\frac{5}{8}$-in. diameter cylindrical brass tube of about 2-in. length couples the unit to a single-stage preamplifier. The latter is contained in a cylindrical housing 2 in. in diameter by 8½ in. long. The useful range of this instrument extends to about 50 kc.

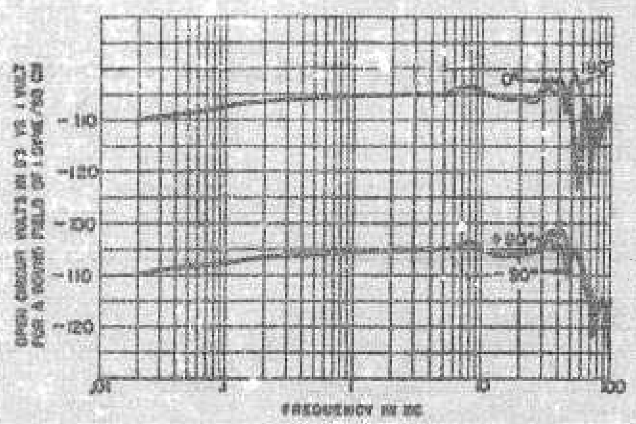

FIGURE 89. Receiving response, TMB-T1 hydrophone.

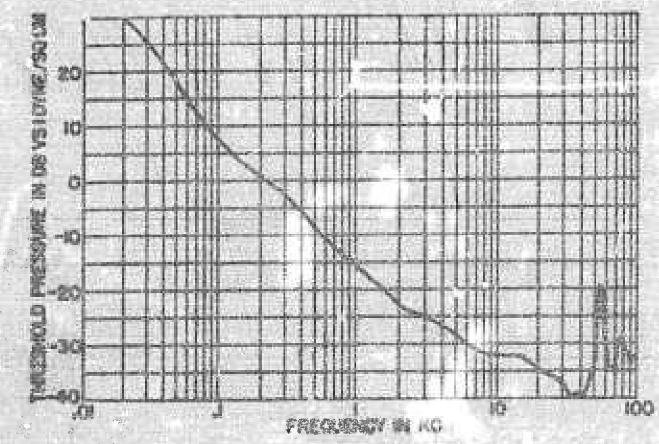

FIGURE 90. Measured threshold, TMB-T1 hydrophone.

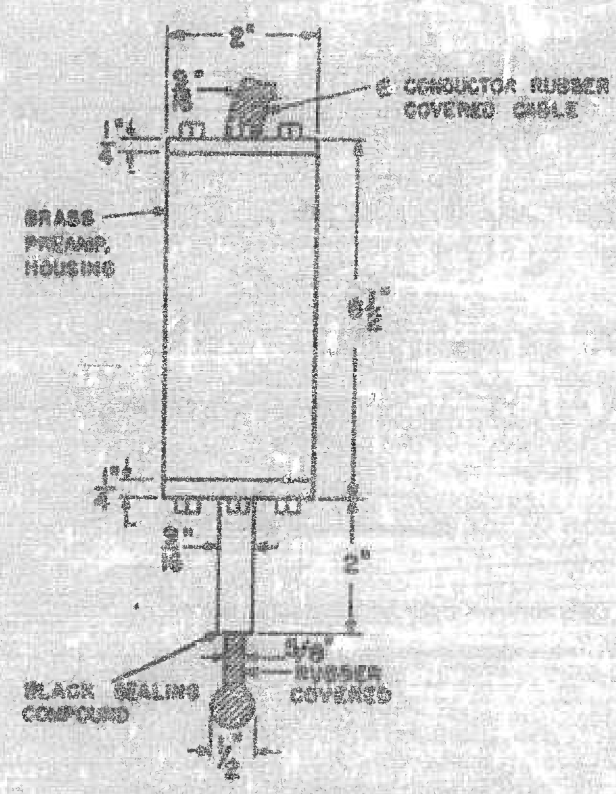

FIGURE 91. TMB-T1 hydrophone.

8.7.3 Stanolind Oil and Gas Company Tourmaline Gauges

Type: X-Cut Tourmaline Crystal.

Designer: Stanolind Oil and Gas Company, Tulsa, Oklahoma.

References: NDRC Report No. 6.1-sr1130-1822, September 8, 1944.[147]
NDRC Report No. 6.1-sr1130-1971, October 31, 1944.[149]

Use: To measure high-pressure underwater sound.

Description: Designs of the Stanolind Oil and Gas Company have been calibrated by the USRL for the Underwater Explosion Research Laboratory at the Woods Hole Oceanographic Institution and for the MIT Underwater Sound Laboratory. These instruments have generally been used by the Navy for underwater explosion measurements.

Either two or four tourmaline disks are employed in each instrument. The diameter of these disks varies between ¼ in. and 1⅝ in. The disks are either ¹⁄₁₆ in. or ⅛ in. thick. The smaller dimensions apply to the instrument with the highest frequency range. The disks are silver and copper plated and welded together. The outside faces are covered with metal foil or gauze for shielding, and are connected to a copper tube which is grounded by the water. If four crystals are used, the midpoint of the pile-up is also strapped to this tube. The other faces are connected in parallel to an insulated conductor inside the tube which forms the high side of the circuit. The crystals are covered with a molded rubber jacket or with DR tape to keep water away from them. A cement, "Bostik," is applied under the cover to exclude air and provide high insulation resistance. In order to minimize electric pickup, it would be preferable if both sides of the crystal were kept off ground and two insulated leads were brought out.

The useful frequency range, depending on the size and construction of the crystal, extends from 50 kc to 1 mc.

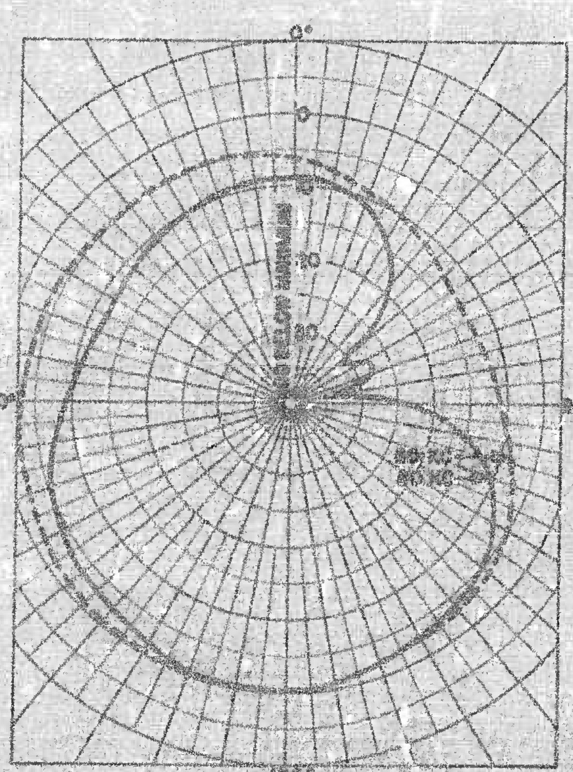

FIGURE 92. Directivity pattern, Stanolind Oil and Gas Company tourmaline crystal hydrophone No. 525.

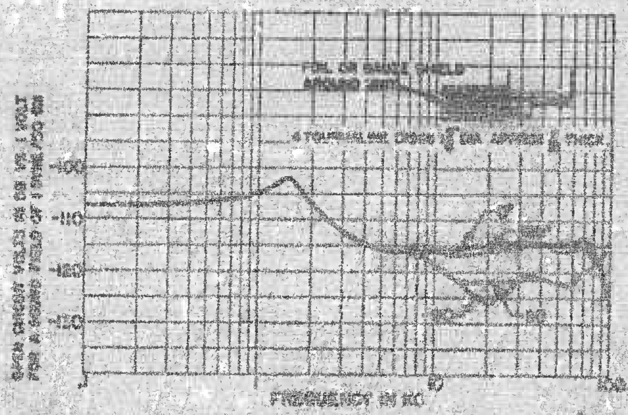

FIGURE 94. Receiving response, Stanolind Oil and Gas Company tourmaline gauge (4 disks).

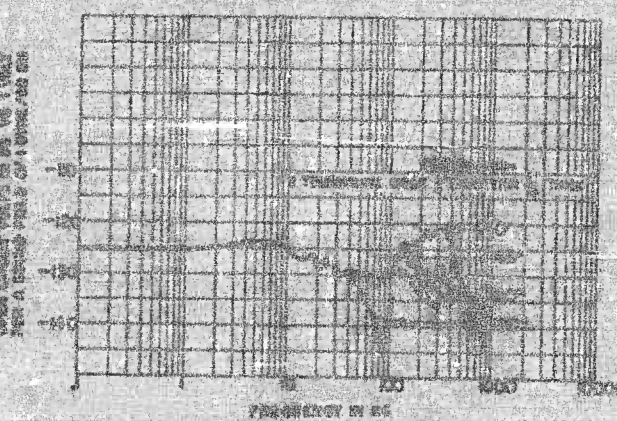

FIGURE 93. Receiving response, Stanolind Oil and Gas Company tourmaline gauge (2 disks).

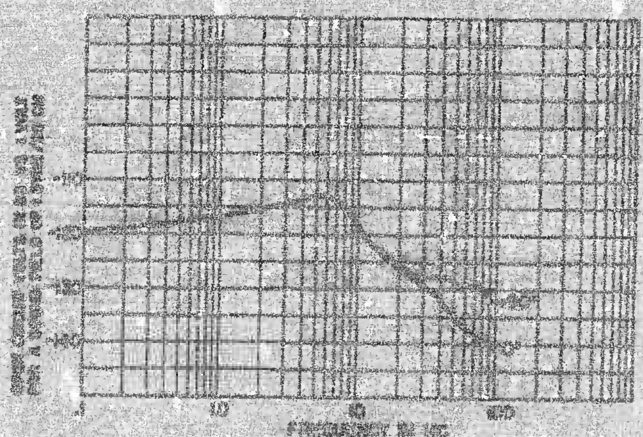

FIGURE 95. Receiving response, Stanolind Oil and Gas Company tourmaline crystal hydrophone No. 525.

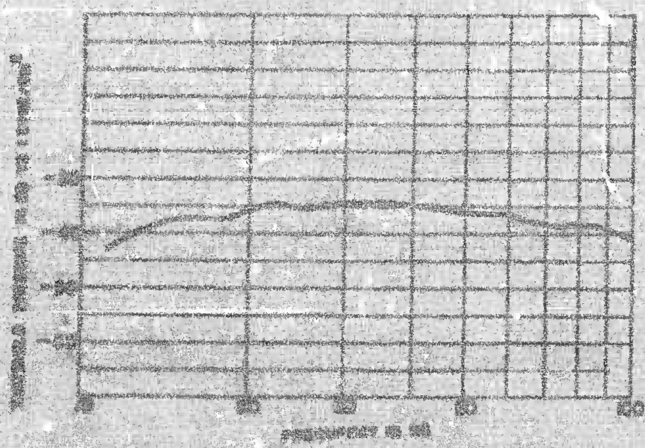

FIGURE 56. Calculated threshold, Stanolind Oil and Gas Company tourmaline gauge (2 disks).

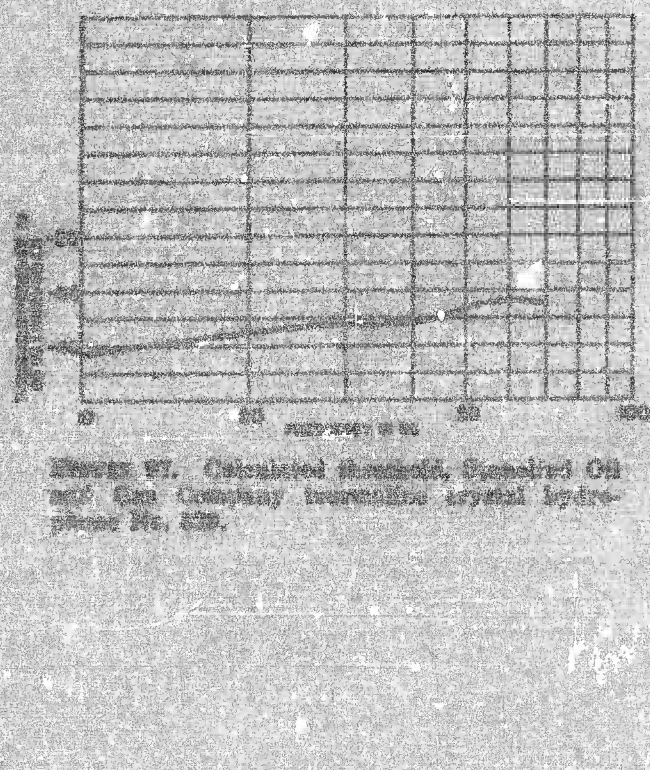

FIGURE 57. Calculated threshold, Stanolind Oil and Gas Company tourmaline crystal hydrophone No. 529.

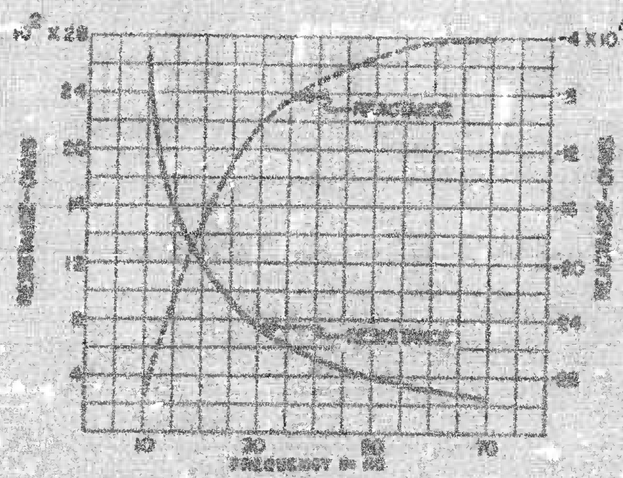

FIGURE 58. Impedance, Stanolind Oil and Gas Company tourmaline crystal hydrophone No. 529.

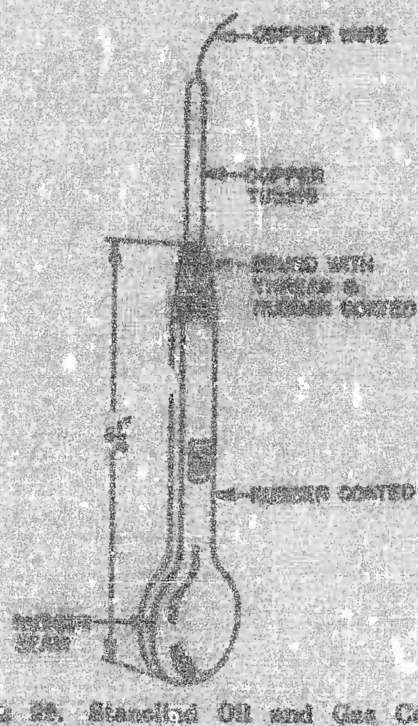

FIGURE 59. Stanolind Oil and Gas Company tourmaline gauge.

6.2 SCANNING SONAR

6.2.1 Introduction

Present types of sonar gear used in echo ranging (see Chapter 2) operate on the "beam" or "searchlight" principle: the emission by a projector at a given bearing of directed supersonic pulses and the reception by the same projector of audibly heterodyned echoes. By repeating this procedure at 5° changes in the projector bearing, the complete (180°) forward sector is covered. When a target is discovered by its echo, its bearing is found by "cut-ons" or the use of BDI.[132] Range information is supplied by the chemical recorder.[132]

Such a procedure requires approximately 2.5 min for the complete coverage of the 180° sector by successive pings of the searchlight beam. Disadvantages result from the difficulty encountered by the beam in keeping on a target (in part eliminated by BDI), from the possibility that a target may be much closer than the maximum attainable range before detection due to the time required to cover the sector by pinging, and finally, from the comparatively low search efficiency[133] for a given maximum range due to the small number of pings emitted in any given direction.

As a result, scanning sonar systems have been developed by HUSL and by UCDWR to maintain sensitivity in all directions simultaneously through a rapid continuous scanning of wide azimuth sectors of 180° or more. Theoretically, this should permit detection of all targets within the maximum available range.

In addition, the scanning sonar systems are designed to present a plan position indication [PPI] of all targets within range on the screen of a cathode-ray oscilloscope. This will provide bearing and range information to supplement that supplied by the chemical recorder. The use of visual plan position indicating is intended to permit the maintenance of continuous contact with the target.

Disadvantages incurred by scanning sonar with respect to the conventional searchlight gear are largely due to the relatively high visual recognition differential, and to the high noise level within the rather broad filters of the gear; the smaller acoustic pressure in a given direction, due to the horizontal breadth of the emitted beam, can be overcome by a higher acoustic power output.

This chapter includes a compilation and discussion of the physical characteristics of scanning sonar systems as obtained in USRL tests, and a general analysis of the expected operational effectiveness of scanning sonar in echo ranging versus submarines as determined by these characteristics, particularly the corresponding effectiveness of conventional searchlight gear.

6.2.2 Harvard University Systems

General Description

Two systems of scanning sonar, capacity rotation [CR] and electronic rotation [ER], have been developed by the Harvard Underwater Sound Laboratory. They operate on the principle of "flooding" the area of interest with sound by periodically pulsing supersonic waves from a projector in all directions in the horizontal plane. A multielement transducer is used, as shown in Figure 100, and during projection all elements are connected in parallel. In reception, the same transducer is made directional and its directivity pattern is rotated at high speed in the horizontal plane. This is accomplished by connecting each element of the transducer to a corresponding element of a scanning switch. The switch couples into a single network the output of a relatively small number of adjacent transducer elements, introducing suitable phase displacement for making these elements into a directional hydrophone. The output of the switch is amplified and applied to the brightness control of a cathode-ray tube so that a spot identifies an echo. Ranges are measured by applying potentials which initiate a diverging spiral sweep in the cathode-ray tube indicator at the instant that the pulse is emitted so that the distance of the spot representing the echo from the center of the screen is approximately proportional to the range of the target producing this echo. By synchronizing the rotation of the spiral sweep with the rotation of the scanning

switch, the spot bearings are made to correspond with target bearings.

The distinction between CR and ER sonar is in the method employed for producing the scanning switch action. In CR sonar this is accomplished by rotation (at 30 rps) of one of a pair of condenser plates relative to the other, the outputs of the transducer elements being connected to the stator plate.

In ER sonar the scanning switch action is purely electronic and makes use of a system of triodes, one for each element of the transducer. These triodes are connected to the transducer elements into a directional hydrophone. The directivity pattern is rotated at the frequency of a low-frequency alternating current (200 to 800 c).

Because of the difference in the methods of producing scanning switch action, it has been found that ER sonar is suited for the use of very short pulses (≈ 2 msec), while CR sonar is readily adapted for pulses sufficiently long for auditory monitoring at a given bearing (≈ 30 msec).

XQHA Capacity Rotation Scanning Sonar

The XQHA CR scanning sonar system provides a means of obtaining a plan position indication of acoustically reflecting objects within the range of its transducer. The system is characterized by the fact that the receiving beam, in effect, is rotated electrically by a commutator arrangement, the transducer being stationary.

The transducer of the XQHA system (see Figures 101, 102) consists of 48 stacks of laminations, each of which may be referred to as an element. (The elements are numbered consecutively from 1 to 48 and are read clockwise when the transducer is suspended in the water from a ship. The 0° axis is taken to be midway between elements No. 48 and No. 1.) When transmitting, each of the elements is connected in series with a tuning condenser (0.012 μf), the 48 units then connected in parallel and finally shunted by a tuning coil. In this arrangement the transducer is connected across the output of the power amplifier. The system on transmitting is hence nondirectional in the horizontal plane. To provide sufficient power to produce pressures in any direction which are equivalent to those provided by conventional directional echo-ranging equipment, an impulse-type driver (see Figure 100) is used which employs large storage condensers for the plate supply of the output power tubes. An exponentially decaying pulse of 25-msec duration with about 3-db attenuation in this time is thus obtained, which has, on the lowest keying rate, a power of about 8 kw, resulting in

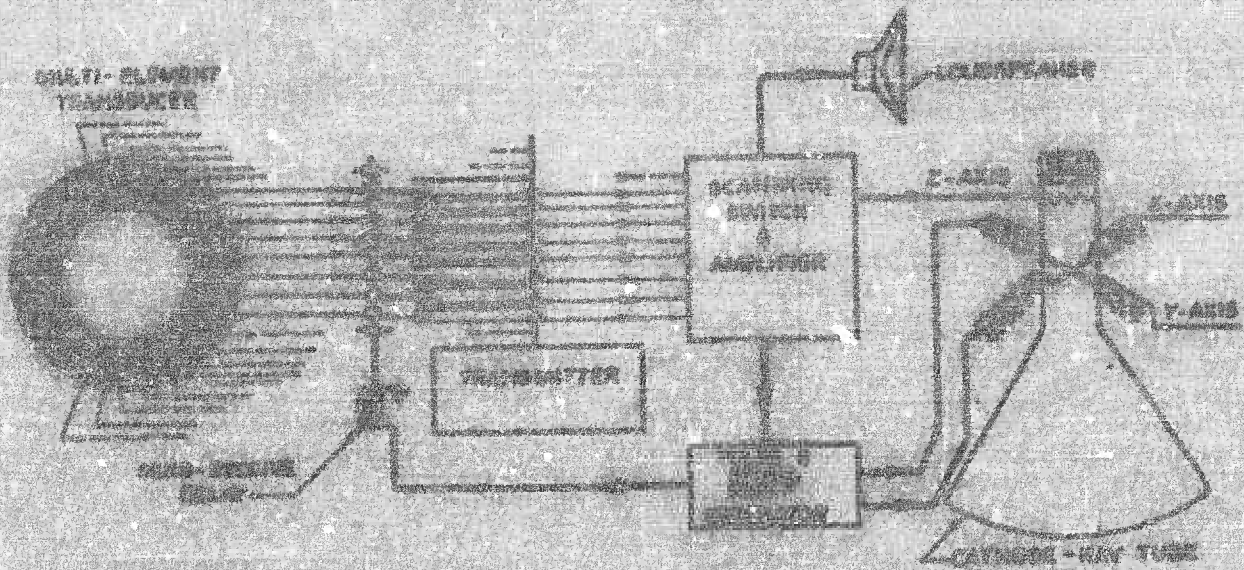

FIGURE 103. Schematic diagram, Harvard scanning sonar showing multielement transducer.

an acoustic power output of about 3 kw. The average power input to the transmitter is about 550 w.

On receiving an entirely different arrangement is used. Each 0.012 μf condenser is shunted across the corresponding transducer

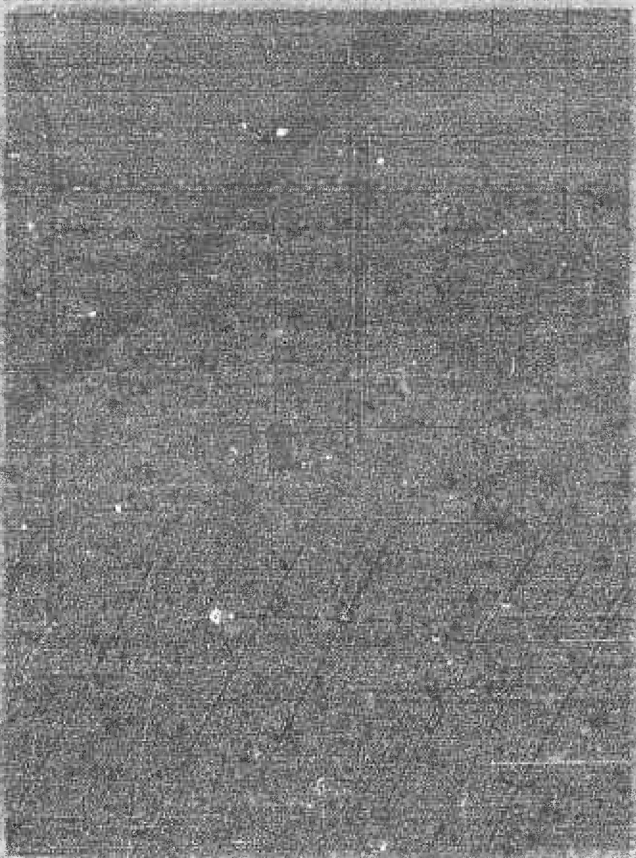

Figure 101. Transducer, XQHA system.

element and the outputs of the elements are then individually connected, each to the input of a small impedance transformer. The 48 transformers are mounted in a circle on a glass disk which forms the stator of a rotating capacity commutator (see Figure 104). The outputs of the transformer are connected to metallized segments (see Figure 105) similarly arranged about the other surface of the glass disk and each forms one plate of a condenser. The rotor consists of a second glass disk similar to the first and mounted on the same axis as the stator with an air gap of 0.0085 in. between them. On the rotor are also mounted 48 metallized segments which form the second plate of the condenser. In scanning operation, the rotation of the rotor successively brings each segment on the rotor opposite each segment of the stator. When a sound wave is incident on the transducer, each element generates a voltage whose magnitude and phase depend upon the orientation of that element with respect to the direction of incidence of the sound wave. To provide directional reception, it is therefore necessary to combine the voltages of a number of elements with proper attenuation and phase shift so that the resultant voltage will be large only when the sound wave approaches from a given direction. This is accomplished by a lag line mounted on the rotor. Sixteen of the metallized segments on the rotor are connected to proper positions along the lag line. By the attenuation and phasing thus produced, the

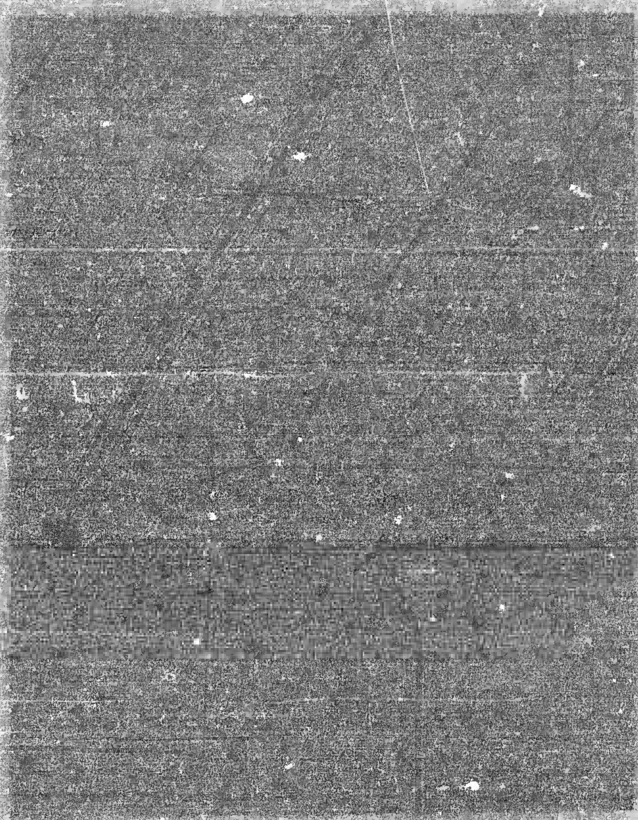

Figure 102. Transducer, XQHA system with rubber cover removed.

output voltage from the lag line will be large only when sound is arriving from a direction within a small angle about the radial line which bisects the 16 elements of the transducer, whose corresponding stator plates are "meshed" with

the sixteen active condenser plates on the rotor. Hence, as far as the output of the lag line is concerned, the receiving system is directional, and the directional pattern on receiving can be rotated, without rotation of the transducer itself, simply by a rotation of the rotor. In scanning operation, the rotor has an angular

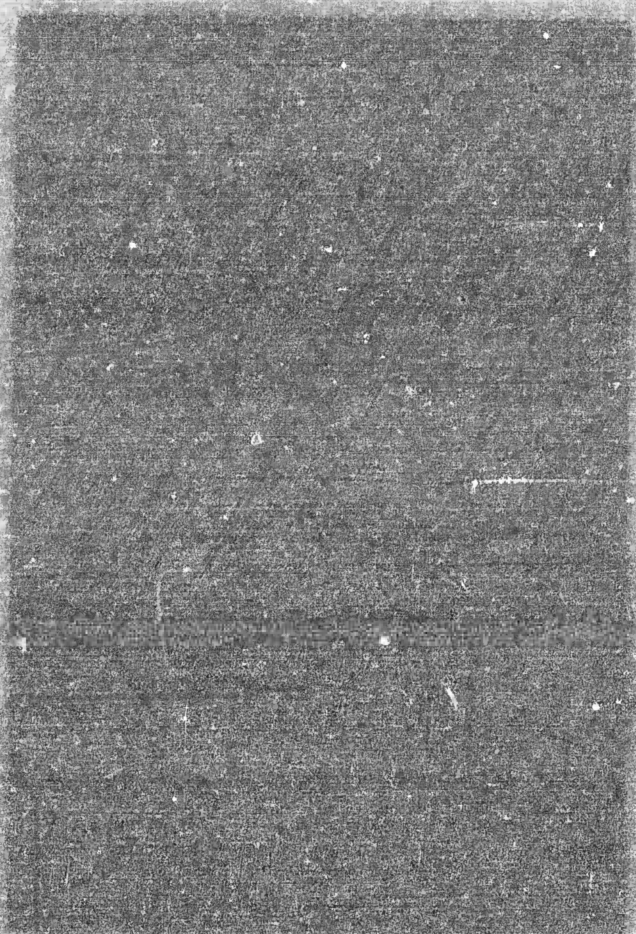

FIGURE [illegible]. Driver, [illegible] system.

velocity of 30 rps, so that the beam on receiving is rotated with a corresponding velocity. The output of the lag line is brought out from the commutator by slip rings and is then applied to a preamplifier. Actually two capacity commutators are employed, operating in parallel from the transducer. The first, described previously, is known as the scanning commutator; the second is identical in construction, except that instead of being rotated at 30 rps by a motor, the position of the rotor is set by a separate servo system to any desired orientation, which may be changed at will by a control on the control panel. This commutator is used for listening steadily in a fixed direction and is hence known as the listening commutator.

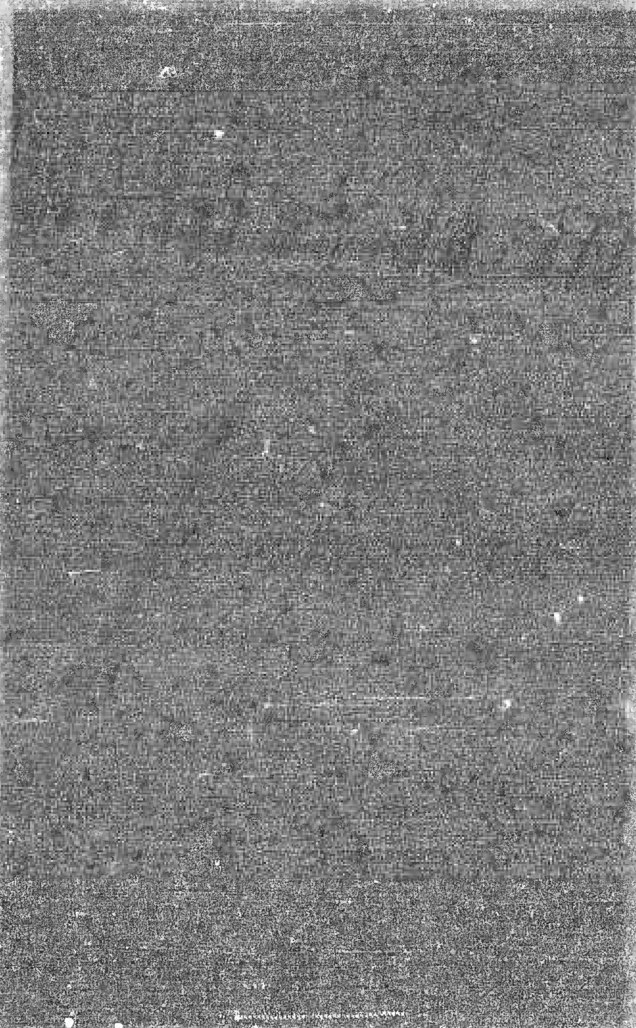

FIGURE [illegible]. Receiver unit, [illegible] system showing rotating capacity commutator.

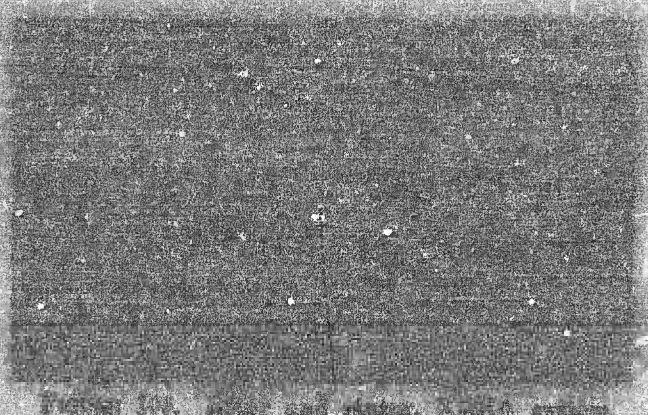

FIGURE [illegible]. Rotor and stator, [illegible] system showing rotating capacity commutator.

Its output is brought out in the same way and goes to another preamplifier.

The output of the scanning commutator, after amplification and rectification, is applied to the brightening grid of a cathode-ray tube (see Figures 106, 107) which provides the plan

rotation on the screen for one rotation of the scanning rotor.

The operation of the scanning system is then as follows: A pulse of 35-msec duration is sent out in all directions from the transducer on transmission. The switch to reception is then

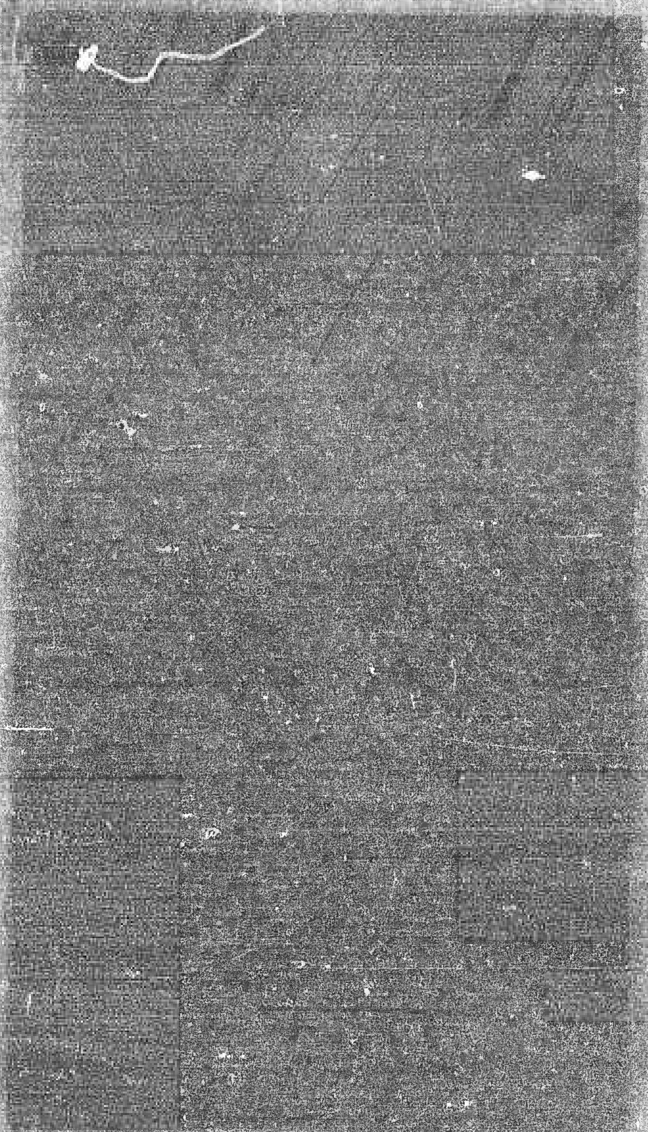

FIGURE 106. Expanded view, cathode-ray tube and indicator-control unit of XQHA.

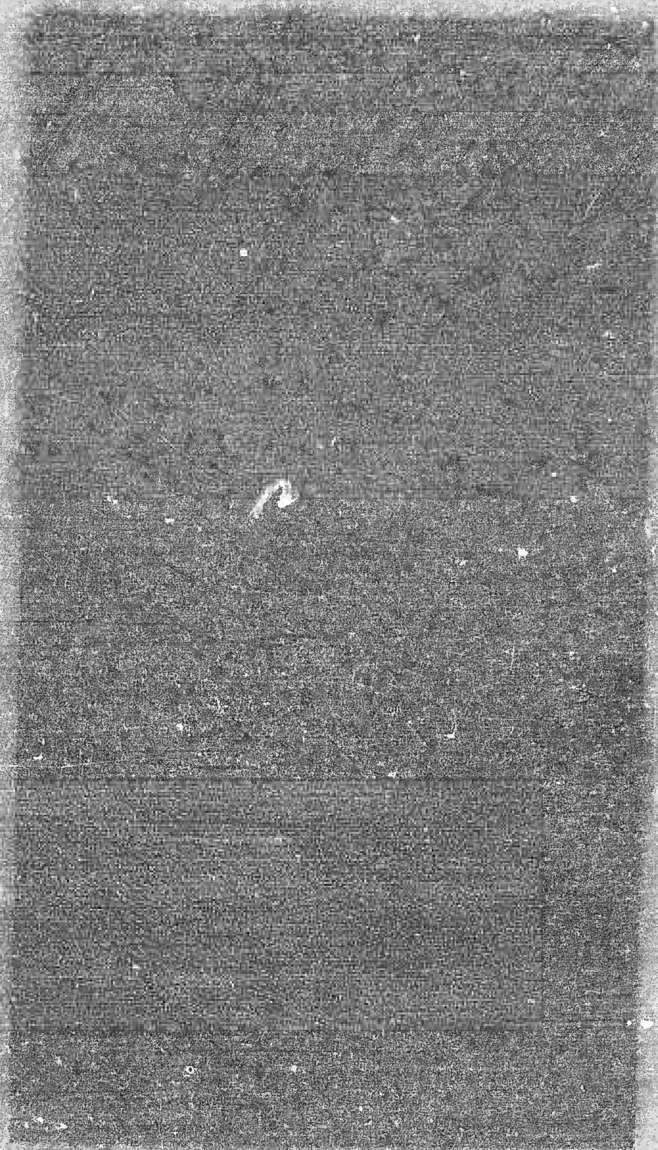

FIGURE 107. Cathode-ray tube and indicator-control unit of XQHA.

position indication. An expanding spiral sweep is provided to this tube, so that between the transmission of one pulse and the succeeding one, the spot on the screen scans out the area of the screen in a spiral from center to edge. The sweep is synchronized with the rotation of the scanning rotor so that the spot makes one

made. If a target is present at some orientation, an echo will reach the transducer from this direction at some later time. The rotating receiving beam will pick up the echo on one of its rotations at this time and this signal will then be transmitted to the brightening grid of the screen. In the meantime, the spot (that

is the potential position of the spot) will have traveled out in a spiral from the center of the screen to a radius proportional to the time since the pulse was transmitted into the water. When the echo is received, the brightening grid is activated, and hence a bright spot (actually a small arc) appears on the screen at a distance from the center proportional to the range of the target and at some characteristic orientation which gives the bearing of the target. If a number of targets are present, each will appear on the screen in its proper position with respect to range and bearing. Hence a map of all acoustically reflecting objects lying within acoustic range of the transducer will be presented on the screen almost continuously (one remapping for each transmitted pulse). Various refinements are present in the system, but they will not be discussed here.

The listening channel is employed differently. The output of the listening commutator after amplification goes to a loudspeaker, thus presenting audio reception of the echoes from the direction to which the listening commutator is oriented. Means are also provided to indicate by an electronic cursor on the cathode-ray screen the direction to which the listening rotor is sensitive. Thus, when an echo appears on the screen, the listening rotor can be aligned in the direction in which the echo was received as shown on the screen, and hence, both visual and aural reception for the same target can be achieved.

Results of USRL Calibration Tests on XQHA Capacity Rotation Scanning Sonar[161]

The USRL has carried out extensive calibration tests on the transmitting and receiving responses, the directivity, the impedance, and the efficiency of the XQHA system. These tests are summarized as follows.

Table 1*

Directivity index on transmission	−11.5 db
Directivity index on reception (effective)	−20.0 db
Projector efficiency of transducer—untuned (at low electric power input)	− 7.0 db (20%)
Projector efficiency of transducer—tuned (at low electric power input)	− 4.2 db (38%)
Projector efficiency of single transducer element (No. [illegible])—untuned (at low electric power input)	− 2.4 db (65%)
Projector efficiency (at full electric power input of 11 kw)	− 7.4 db (18.2%) (acoustic power output = 2 kw)
Output pressure at 1 meter in db vs 1 dyne per sq cm (at full electric power input of 11 kw)	+115.3 db

* All values refer to resonant frequency ~25.5 kc.

Transmitting Tests on Transducer Alone—All Transducer Elements Connected in Parallel

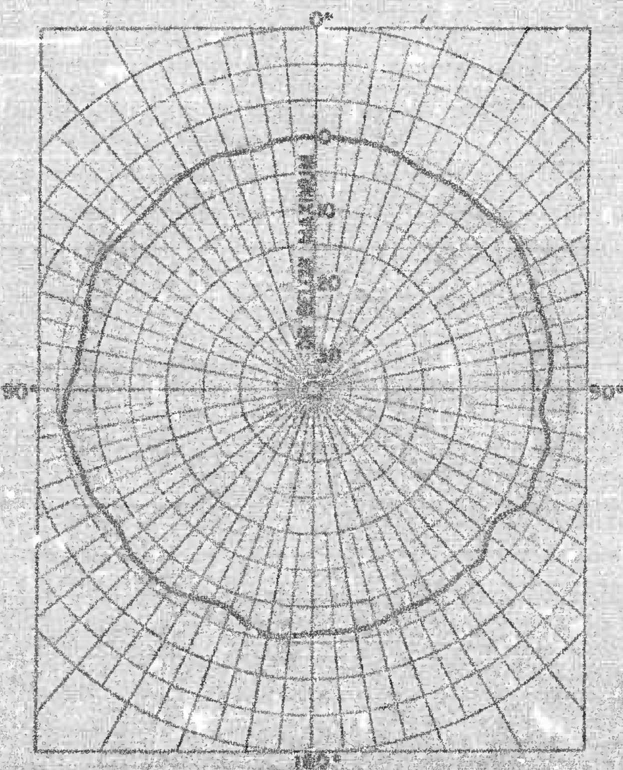

FIGURE 108. Directivity pattern, XQHA transducer with all elements in parallel in horizontal plane at 25.5 kc.

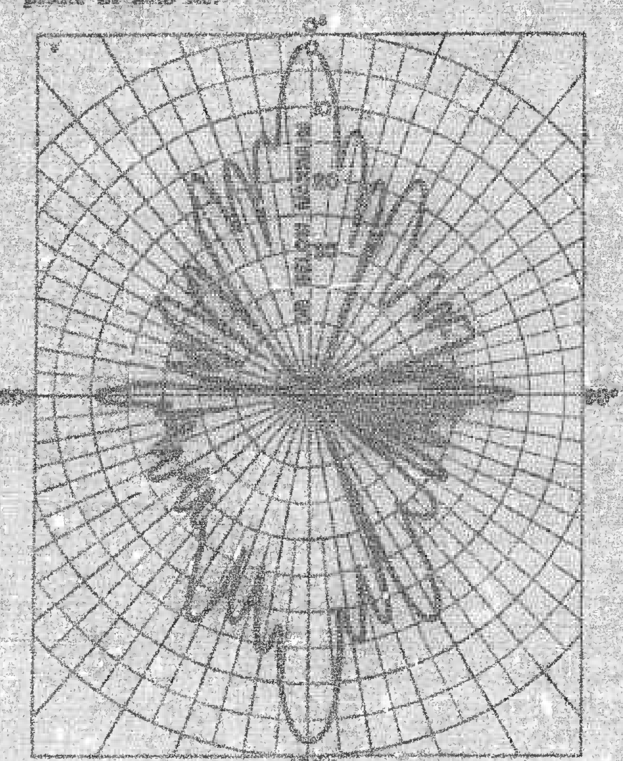

FIGURE 109. Directivity pattern, XQHA transducer with all elements in parallel in vertical plane at 25.5 kc.

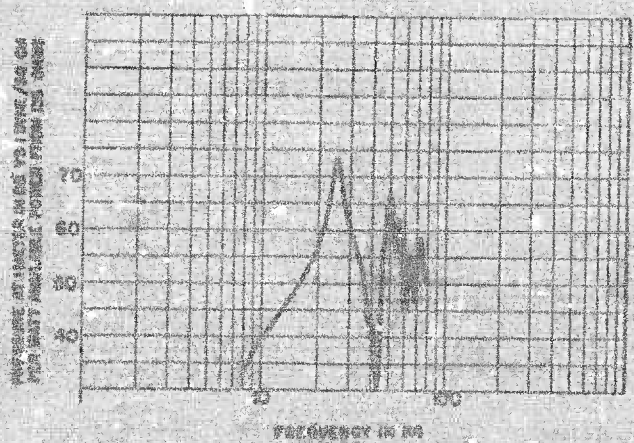

FIGURE 110. Transmitting response, XQHA transducer with all elements in parallel.

Transmitting Tests on Transducer with Associated Tuning Circuits

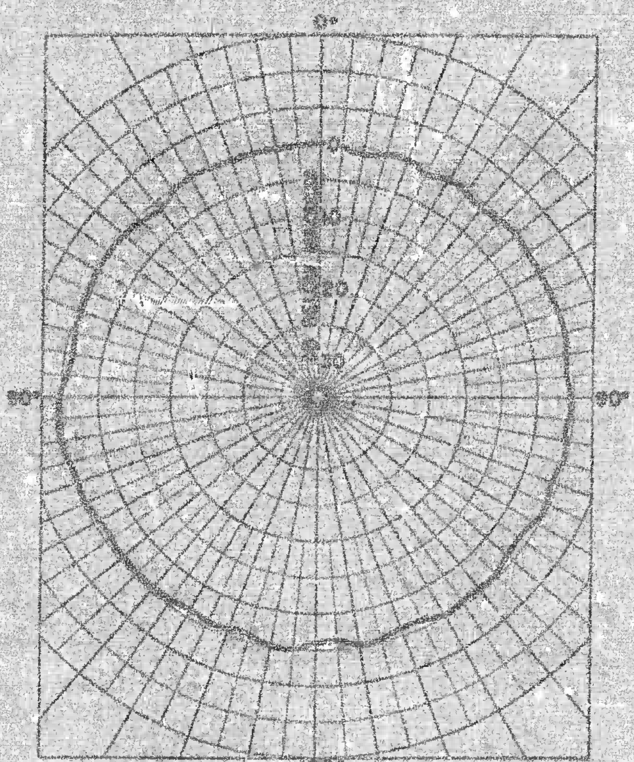

FIGURE 111. Directivity pattern, XQHA transducer with associated tuning circuits in horizontal plane at 26 kc.

Receiving Tests on the Transducer Alone

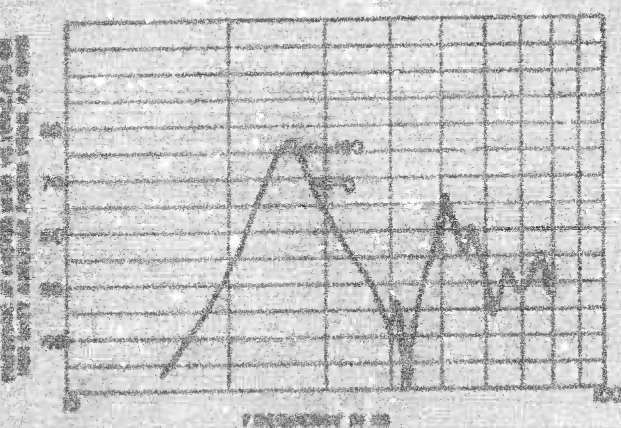

FIGURE 112. Transmitting response, XQHA transducer with associated tuning circuits.

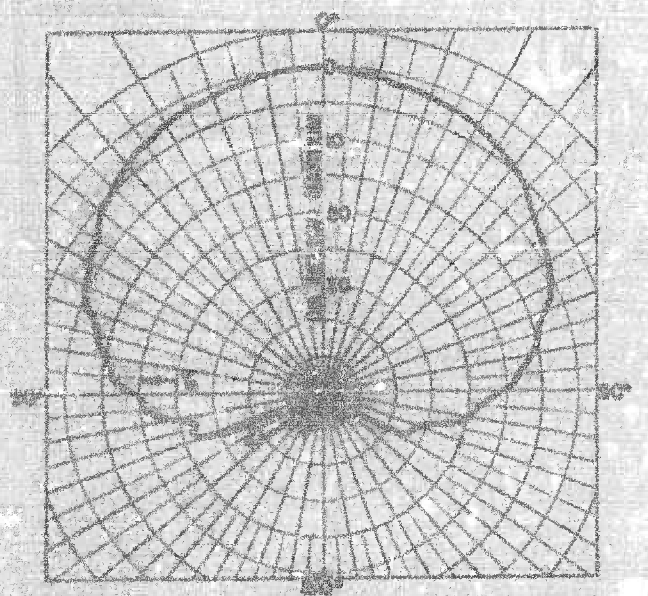

FIGURE 114. Directivity pattern, single element of XQHA transducer in horizontal plane at 25 kc. The 0° axis of the transducer is indicated by T.

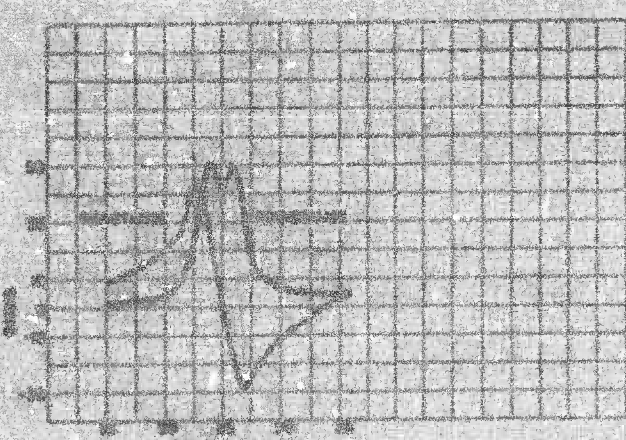

FIGURE 113. Impedance, XQHA transducer with associated tuning circuits.

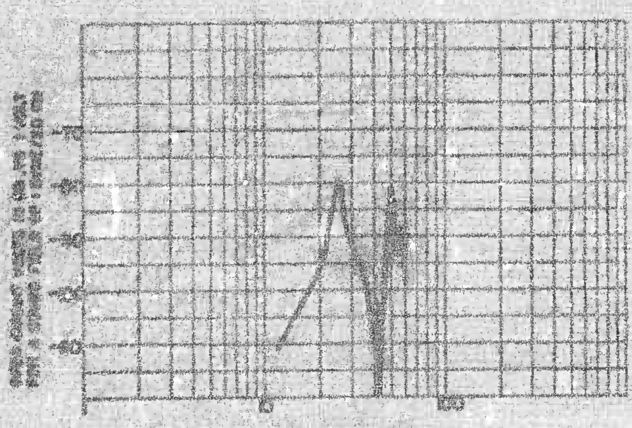

FIGURE 115. Receiving response, single element of XQHA transducer.

Receiving Tests on Transducer with Shunt Condensers, Commutator, and Lag Line[e]

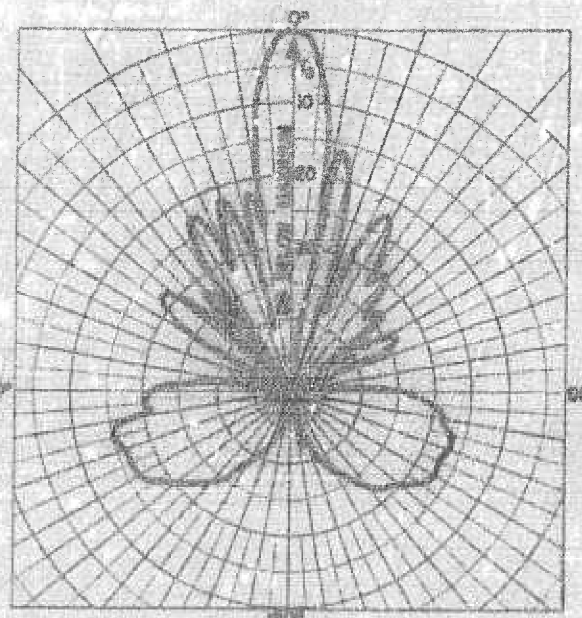

FIGURE 116. Directivity pattern, XQHA transducer in horizontal plane at 26 kc. Transducer rotated with rotor fixed at 0°.

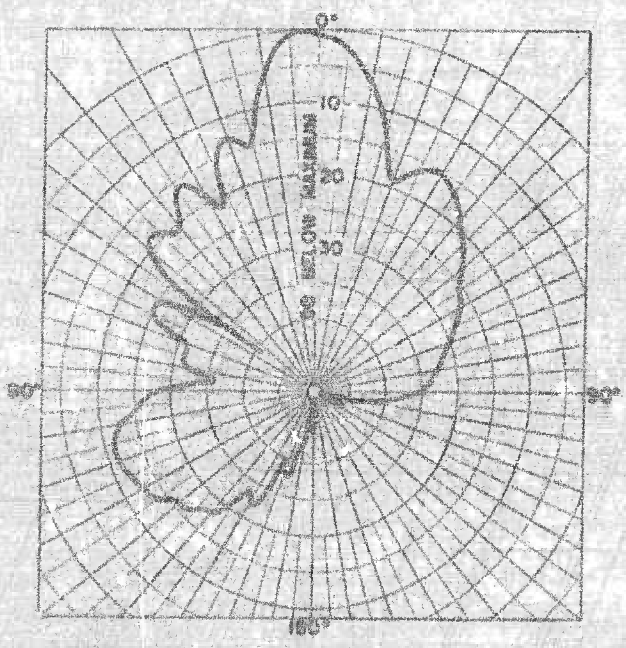

FIGURE 118. BDI directivity pattern, XQHA transducer in horizontal plane at 25.5 kc. Voltage taken at output lag line. Rotor setting at 0°. Left half only.

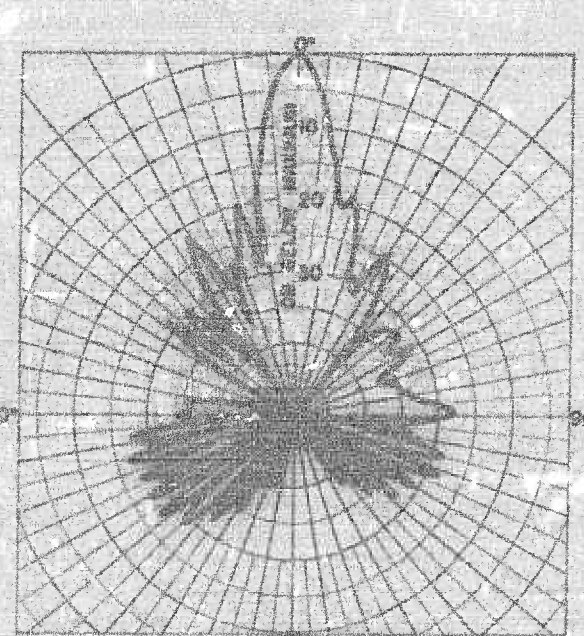

FIGURE 117. Directivity scanning pattern, XQHA transducer in horizontal plane at 25 kc. Source on 0° axis of transducer, listening rotor rotated through 360°.

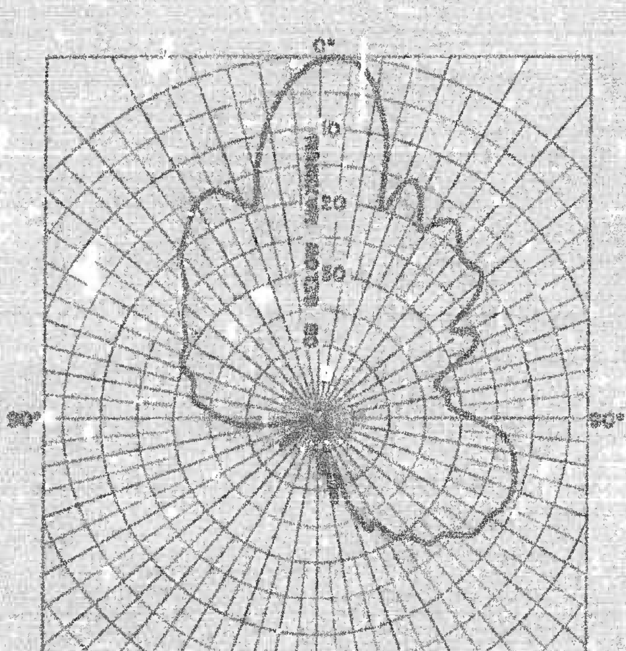

FIGURE 119. BDI directivity pattern, XQHA transducer in horizontal plane at 25.5 kc. Voltage taken at output lag line. Rotor setting at 0°. Right half only.

[e] Measurements made at output of lag line give essentially open circuit voltages applied to input of XQHA preamplifier.

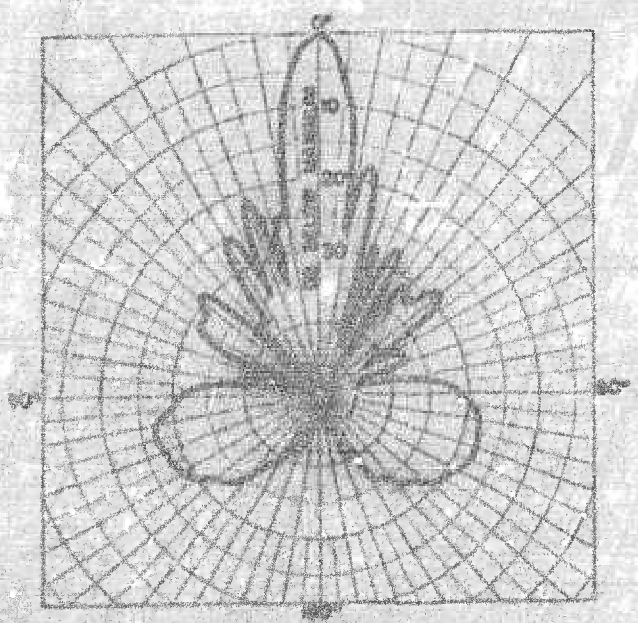

FIGURE 120. BDI directivity pattern, XQHA transducer in horizontal plane at 25.5 kc. Voltage taken at output lag line. Rotor setting at 0°. Parallel aiding.

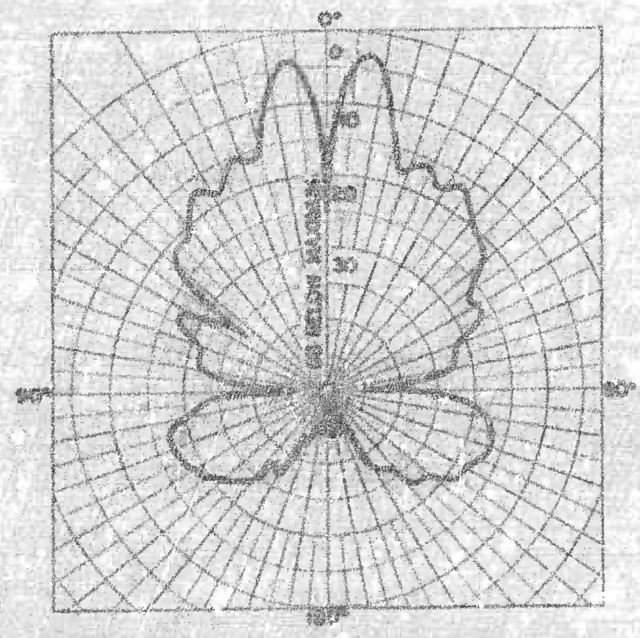

FIGURE 121. BDI directivity pattern, XQHA transducer in horizontal plane at 25.5 kc. Voltage taken at output lag line. Rotor setting at 0°. Parallel opposing.

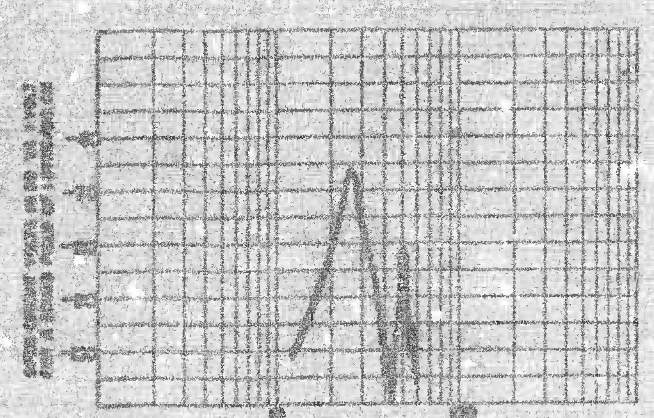

FIGURE 122. Receiving response, XQHA transducer with rotor set at 0° and sound incident along the 0° axis of the transducer. (0° position of rotor is taken to be that for which the 16 active condenser plates of the rotor are in register with elements 41 to 48 and 1 to 8 inclusive, so that the beam pattern theoretically has its maximum along the acoustic 0° axis of the transducer.)

Tests on Transducer Driven by XQHA Oscillator (Full Electric Power Input)

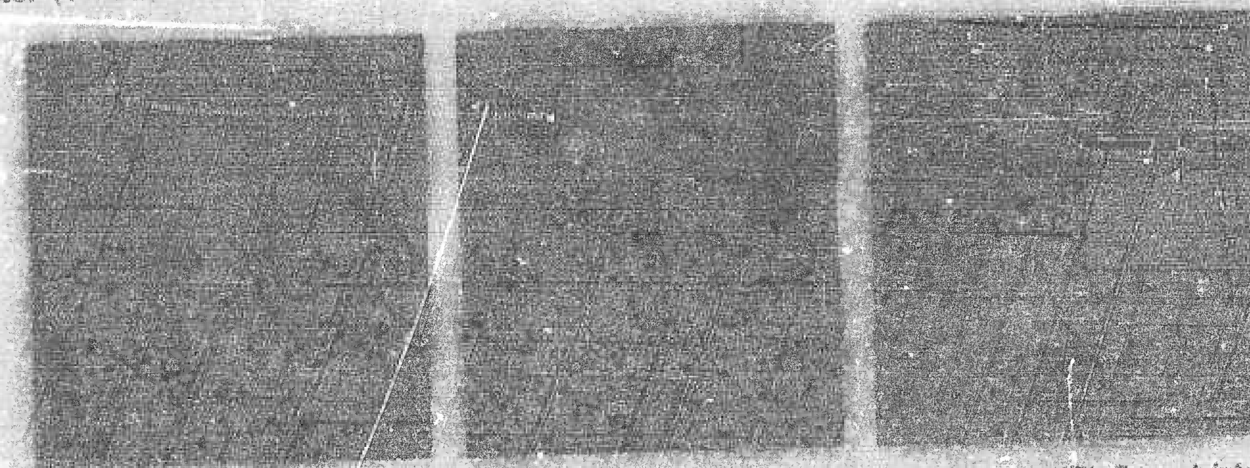

FIGURE 123. Wave form of the (30 msec) pulse. (A) Voltage applied to transducer. (B) Current into transducer. (C) Acoustic pulse in water as measured by a hydrophone.

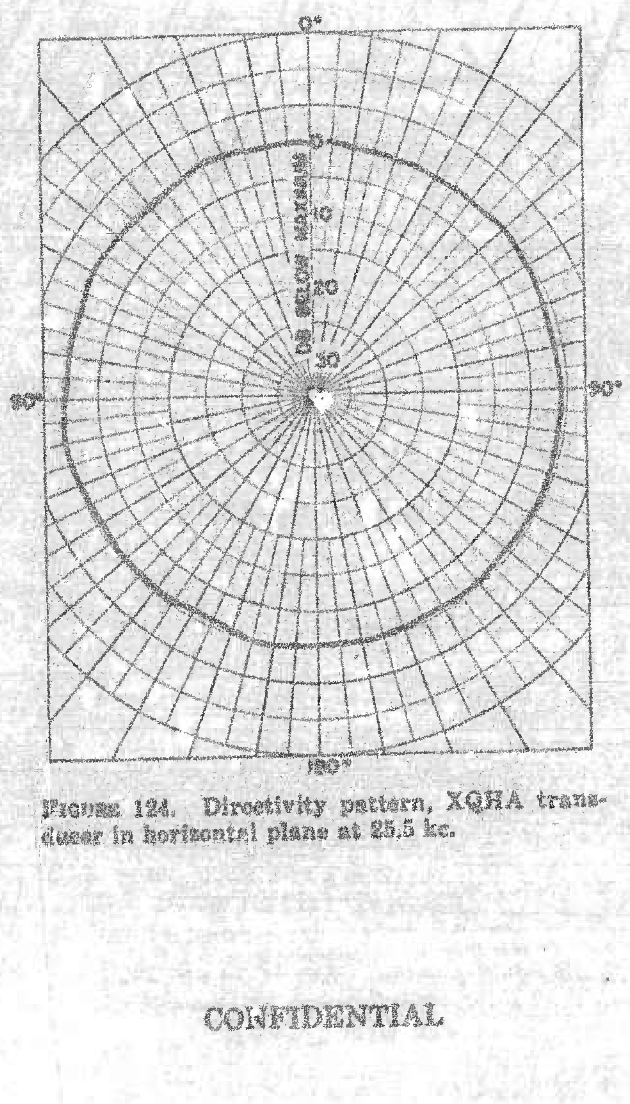

FIGURE 124. Directivity pattern, XQHA transducer in horizontal plane at 25.5 kc.

Test on Scanning Channel Circuits

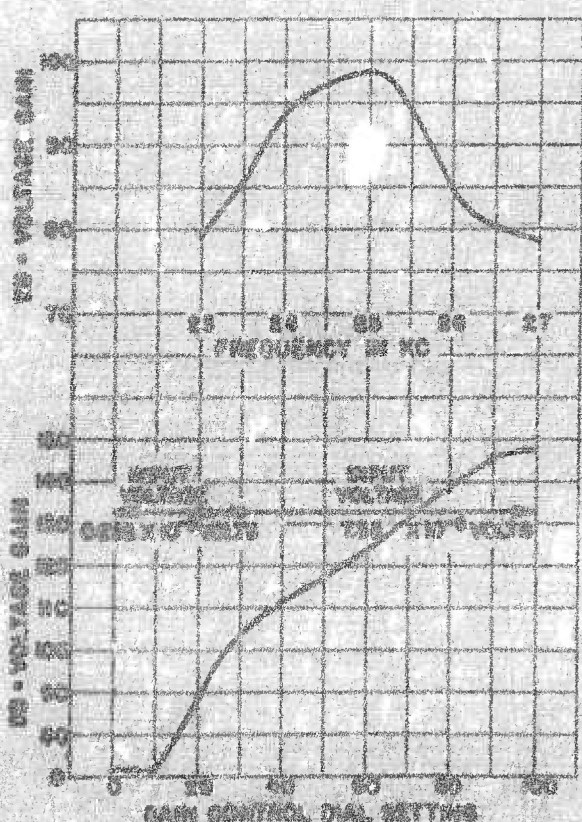

FIGURE 125. Gain in scanning channel from a-c voltage input to scanning preamplifier to d-c voltage on brightening grid of cathode-ray oscilloscope, as a function of (1) frequency (gain control setting at 26.5 kc) and (2) gain control setting (frequency at 25 kc).

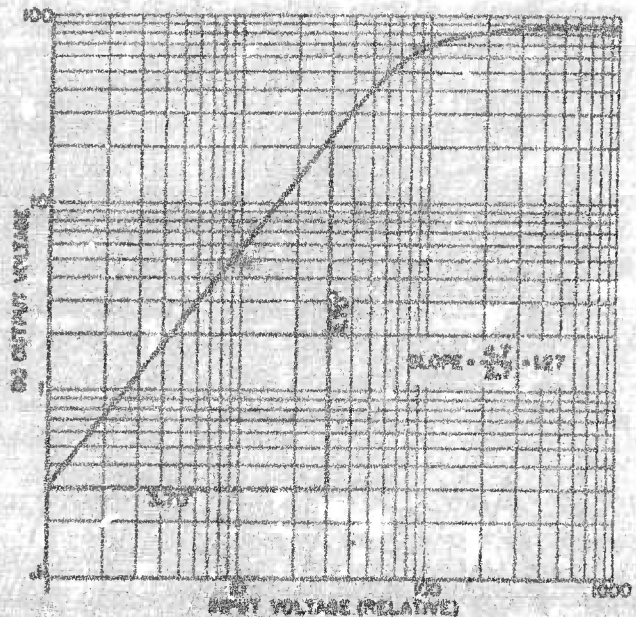

FIGURE 126. Relation between a-c voltage applied to preamplifier and d-c voltage of brightening grid of cathode-ray oscilloscope at 25.5 kc.

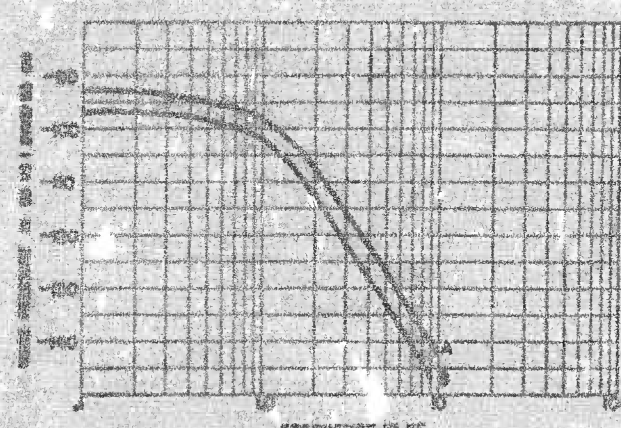

FIGURE 127. Noise developed by system and appearing on brightening grid of cathode-ray oscilloscope (gain control 90 kc; frequency 25.5 kc: (1) entire system in operation with scanning motor running, (2) entire system in operation with scanning motor shut off.

Dynamic Scanning Directivity Pattern. The dynamic scanning directivity pattern is the variation of voltage on the brightening grid as a function of time when correlated with the angle between the orientation of the source and the instantaneous direction of maximum sensitivity of the beam. The dynamic scanning directivity pattern is not identical with the scanning directivity pattern giving the a-c voltage at the output of the lag line (see Figure 128)[d]

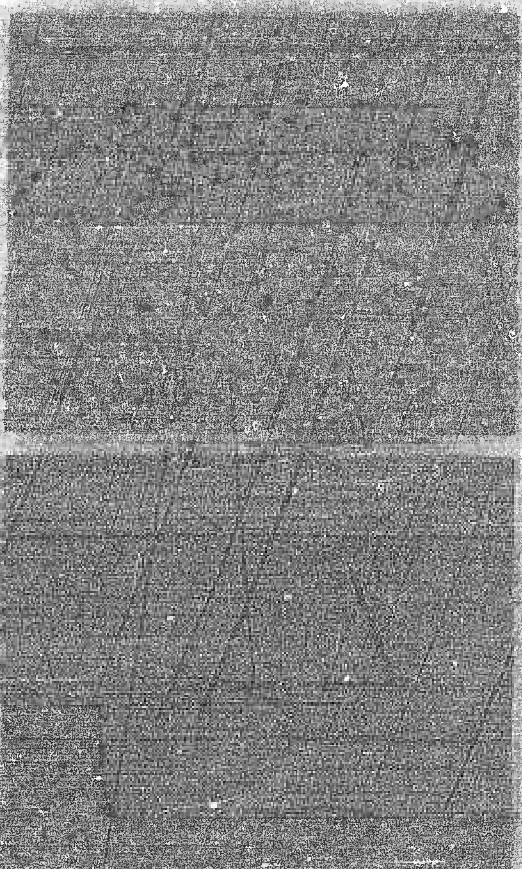

FIGURE 128. Wave forms as rotating beam traverses the sound source: (A) a-c signal at output of lag line. (B) d-c signal applied to brightening grid of cathode-ray oscilloscope.

because of the nonlinear action of the rectifier. This nonlinear action serves to suppress side lobes.

Bearing Accuracy Tests. The USRL has also made tests on the bearing accuracy of XQHA scanning sonar for visual observation on the oscilloscope screen and with use of the associated BDI circuit. Both methods gave target bearings (the target was an independent sound source) with errors of the order of 1 degree. At least part of the bearing error seemed to arise from improper positioning of the listening rotor by the synchro systems.

[d] A 1-kc tuning signal is superimposed on the photographs.

ELECTRONIC ROTATION SCANNING SONAR

In addition to the CR scanning sonar discussed above, Harvard University has also developed an electronic rotation scanning sonar. As has already been mentioned, in this device the receiving beam is rotated electronically rather than mechanically. As a result of the rapid rate of rotation which is necessary because of the electronic rotation, a very wide pass band in the scanning channel ($\approx$ 8 kc) is required for ER scanning sonar; as a result, a noise level inherently higher than in CR scanning sonar is always present.[e]

The USRL has calibrated an early model of ER scanning sonar obtaining response and directivity patterns. However the equipment has never worked very well and, it is understood, has been superseded by more satisfactory types.

6.8.3 University of California System

FREQUENCY MODULATED SONAR

Frequency Modulated [FM] sonar is a device for presenting a plan position indication of underwater objects within sonic range of the equipment. It is designed for installation on both submarines and surface vessels, e.g., A/S craft.

Other vessels and their wakes, mines, torpedoes, sand banks, antisubmarine nets, in fact, any partially or completely submerged objects which are good supersonic reflectors, are represented both audibly, by a constant pitch tone, and visually, by illuminated spots on a PPI oscilloscope screen in their proper position relative to the operating ship.

The operation of FM sonar equipment is as follows: An acoustic signal with a sawtooth

[e] The width of the pass band of [illegible] scanning channel of CR sonar (reckoned to the 10 [illegible] points) is about 2 kc. See Figure 124.

frequency modulation is injected into the water. The difference in frequency between an echo received from an object in the water and the signal being emitted at any instant is then a measure of the range of the object. The equipment can be broken down into the following components, each of which will be discussed separately (see Figure 129):

1. Oscillator (and associated power amplifier).
2. Sound head.

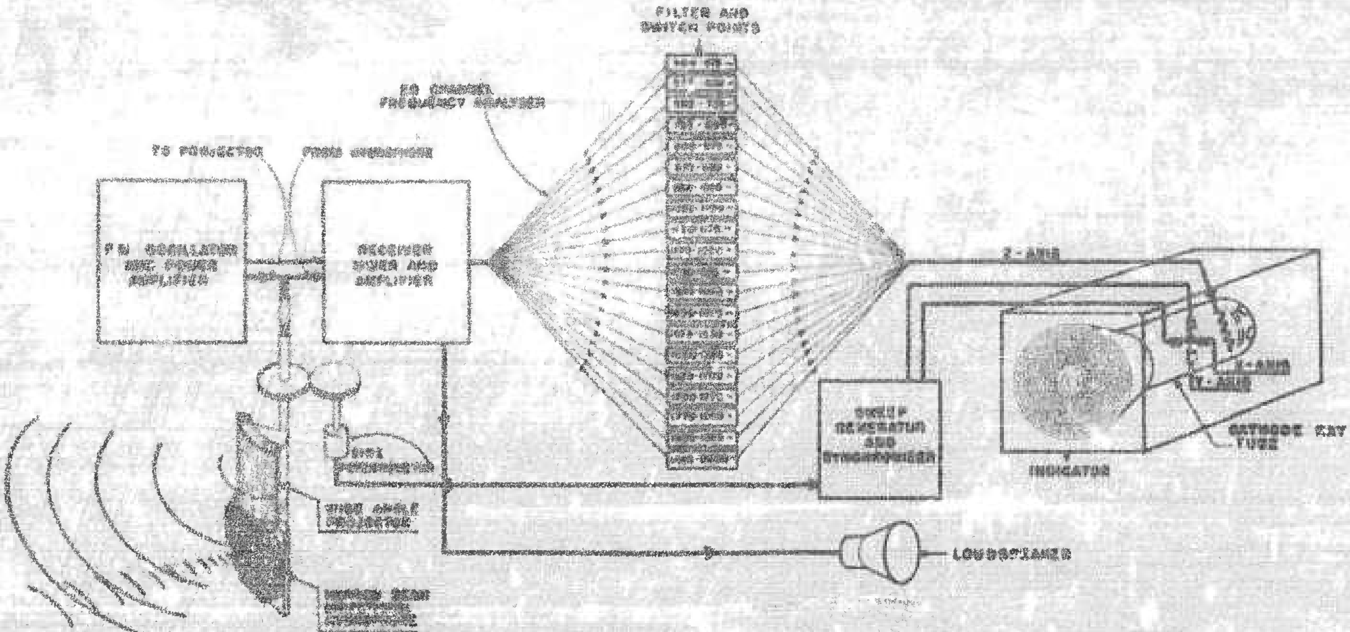

FIGURE 129. Schematic diagram, FM sonar system.

3. Receiving circuit (modulator and amplifier).
4. Analyzer.
5. Indicator.

Oscillator. The oscillator circuit consists of a regulated 370-v power supply, a linear sawtooth oscillator, a positive-bias multivibrator, a low-pass filter, and a push-pull amplifier which is used to blank the signal during the recycling or "flyback" in the sawtooth. The frequency of the output signal from the multivibrator is governed by the voltage applied to its grid return. Since this voltage is a linear sawtooth voltage from the linear sawtooth oscillator, the output will be a sawtooth frequency-modulated signal. The harmonics of the multivibrator output are eliminated by the low-pass filter. The push-pull amplifier is so arranged as to blank the output signal during the time in which the "flyback" on the sawtooth takes place. The rate of repetition of the sawtooth is governed by a resistor which may be varied in three steps by the operator so as to give sawtooth periods of 4.5, 9, and 18 sec, respectively. This provides an adjustment for the range of the target. Thus the oscillator as a unit produces a linear sawtooth frequency-modulated signal with frequency variation from about 35 to 48 kc, and with a sawtooth period which may be adjusted to the three values of 4.5, 9, or 18 sec. Part of the output of the oscillator is applied to the power amplifier and part is used as the injection voltage in the modulator.

Power Amplifier. The power amplifier is a push-pull design with a rated power output of 250 w. A potentiometer output control is included but the amplifier is normally operated at maximum gain.

Sound Head. The sound head is a cylinder 31 in. long, covered by a rubber sleeve, which contains both the transmitter and receiving hydrophone (see Figure 130). The units are mounted on a flange on a standard QC column. The transmitter consists of an array of ADP crystals whose active surfaces form part of a

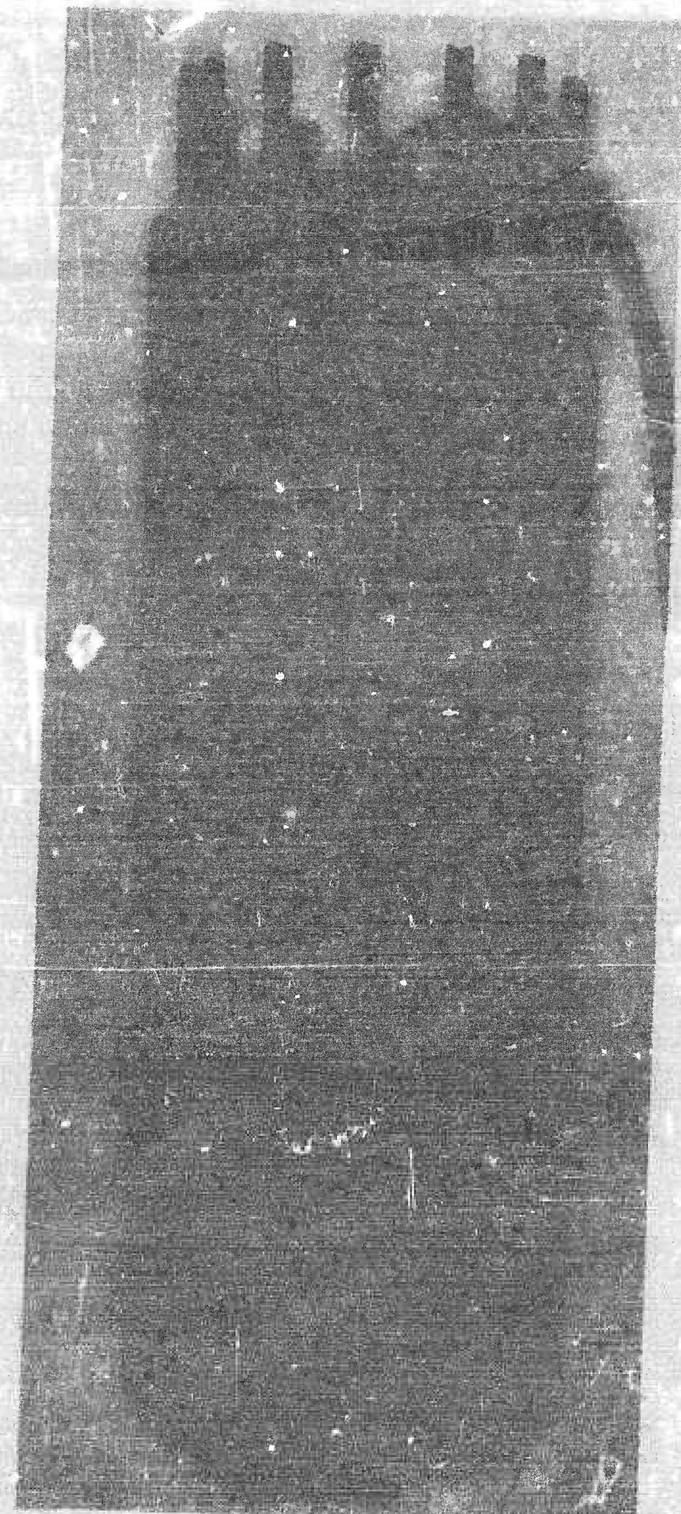

FIGURE 130. Sound head (FM sonar).

cylindrical surface so as to give a beam width in the horizontal plane of about 80°. The beam width in the vertical plane is about 12°. The hydrophone consists also of an array of crystals, but in this case the active surface is a circle 9 in. in diameter. Its beam is sharply directional with a beam width of about 12°. Both transducers are rigidly mounted to the shaft with their axes parallel, and they may be rotated together through a full 360°.

The sound head is trained by a motor which, under ordinary operation, rotates it through 540° (1½ revolutions), whereupon a reversing switch causes it to be rotated back through 540°; reversal again takes place and the cycle is repeated regularly. The rate of rotation may be adjusted to between 2 and 4 rpm. The operator may also arrange to scan only a limited sector, or reverse the rotation direction at any instant.

The transmitter is driven by the power amplifier, while the hydrophone signal is applied to the receiving circuit.

The operation of the units in practice is the following. When the sawtooth frequency-modulated signal is applied to the transmitter, sound is emitted into the water with a sawtooth frequency modulation over a sector 80° wide. If there is a target present, the reflected signal

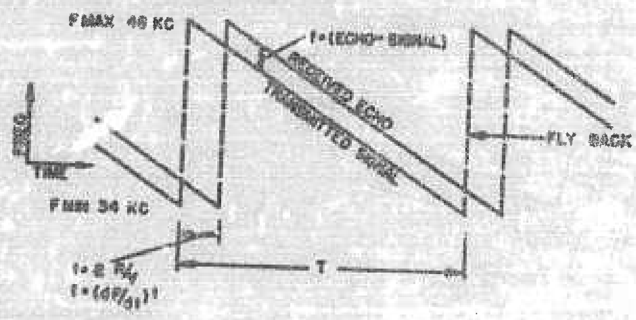

FIGURE 131. Frequencies of emitted and received signals as functions of time.

from the target at the time it reaches the hydrophone will differ in frequency from that being emitted at that instant from the projector because of the frequency sweep. The equipment is so arranged that for any sawtooth period setting, the received signal from maximum range will arrive in a time equal to 1/6 of the sawtooth period. These relationships are shown in Figure 131, where the emitted frequency and the received frequencies from targets at maximum range and one-half maximum range are shown as functions of time.

Receiving Circuit. The receiving circuit consists of two components, a varistor detector and an amplifier. The signal received from the hydrophone is first passed through a 36 to 48 kc band-pass filter and then goes to the varistor detector. The detector also receives an injection signal from the oscillator, the frequency of which is the instantaneous frequency of the sound being emitted by the transmitter. The circuit is designed to balance both the signal voltage and injection heterodyne voltage, leaving only the desired difference frequency. This output is filtered to eliminate any other frequency components which may be present. The difference frequency as a function of time is shown in Figure 131. The filter only admits the lower frequency so that the output of the filter is an almost continuous signal of the desired difference frequency. The amplifier to which this signal is applied is designed so that in the important difference frequency range (500 to 2,000 c), it has a rising characteristic of 12 db per octave and falls off rapidly outside these limits. This equalizes the detector output for various ranges, since the hydrophone signal varies approximately inversely as the fourth power of the range. Part of the output from the amplifier is used to operate a loudspeaker and part goes to the analyzer. The loudspeaker is used for aural monitoring by the operator.

Analyzer. The analyzer consists of 20 band-pass filter networks, associated detectors, and an electronic switch. The signal received from the receiving circuit is applied across 20 band-pass filters with series-tuned inputs arranged in parallel. Each filter is a double-tuned, capacity-coupled, band-pass network with a band width of about 75 c. The 20 filters cover the range from 500 to 2,000 c. Thus, the difference frequency from any target will pass through one (or possibly two) of the filters, the particular filters through which it passes depending on the difference frequency which in turn is a function of the range.

The output of each filter is connected through a potentiometer to a corresponding detector, the potentiometers allowing equalization of the various filter outputs. The detectors are so arranged that they are relatively insensitive to signals of longer or shorter duration than an echo from a target as the transmitter is trained past it. This results in better discrimination against noises of short duration and reverberation. The output from the detectors is used to control the acceleration potential in the cathode-ray tube of the indicator, and thus it controls the brightness of the spot. However, the outputs are not fed directly to the indicator but are applied in sequence by an electronic switch. The output of each filter is allowed to activate the indicator only for a short time in each 1/60 of a second. The sequence is that of increasing target range. The electronic switch is synchronized with the radial sweep on the oscilloscope so that the range is a linear function of distance of spot from the center of the screen.

Indicator. The indicator consists of a cathode-ray tube, a radial sweep circuit, and an amplifier. The amplifier is used to amplify the output from the analyzer detectors for application to the beam intensity control grid of the cathode-ray tube. The radial sweep of the spot on the oscilloscope, as stated, is synchronized with the electronic switch of the analyzer. A sine potentiometer mounted on the shaft of the sound head diverts the radial sweep in a direction determined by the orientation of the sound head at the time. The net result on the screen is an almost continuous plan view of the surrounding area with bright spots representing the presence of acoustically reflecting objects.

Results of USRL Calibration Tests on Frequency Modulated Scanning Sonar[152]

The USRL has carried out detailed calibration tests on the transmitting and receiving responses, the directivity, and the impedance of the FM scanning sonar. These tests are summarized as follows.

Calibration of Transmitter.

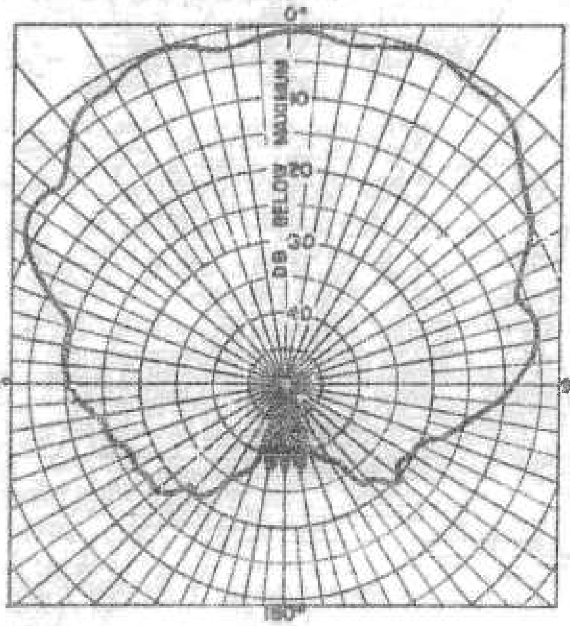

FIGURE 132. Directivity pattern, FM sonar transmitter in horizontal plane at 34 kc.

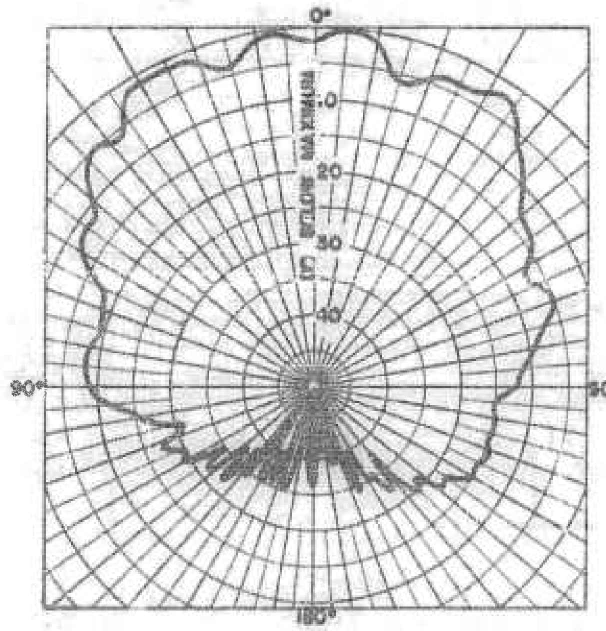

FIGURE 134. Directivity pattern, FM sonar transmitter in horizontal plane at 50 kc.

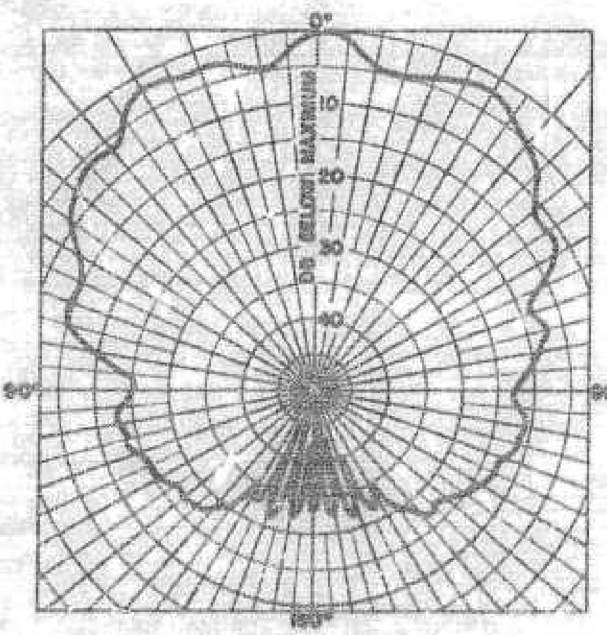

FIGURE 133. Directivity pattern, FM sonar transmitter in horizontal plane at 42 kc.

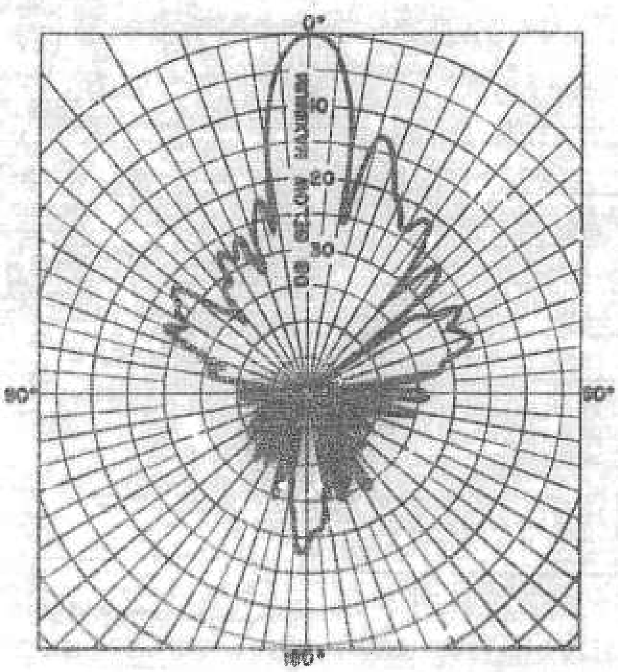

FIGURE 135. Directivity pattern, FM sonar transmitter in vertical plane through acoustic axis at 34 kc.

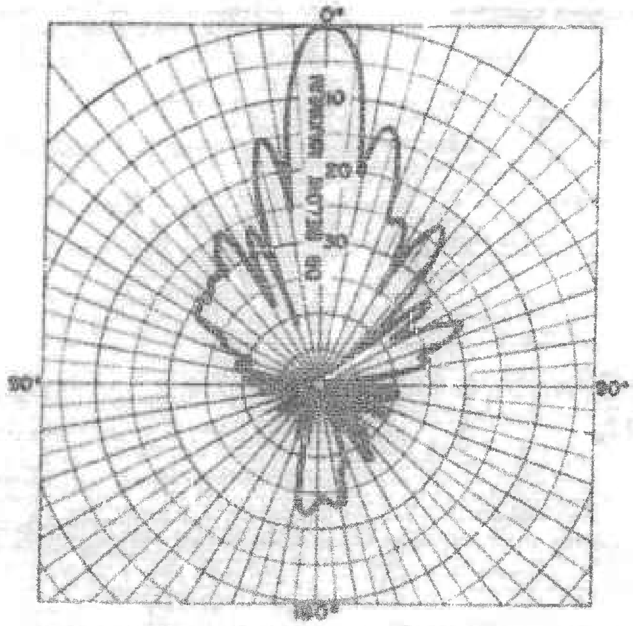

FIGURE 136. Directivity pattern, FM sonar transmitter in vertical plane through acoustic axis at 42 kc.

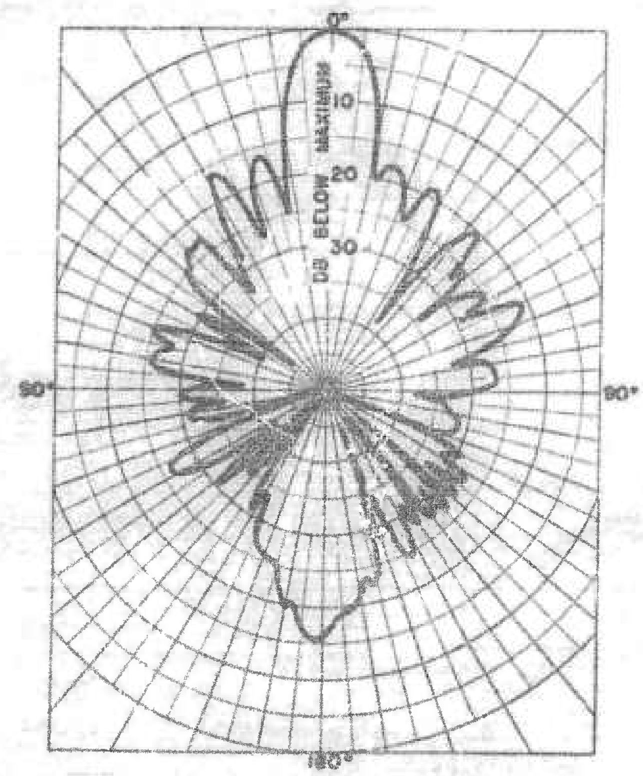

FIGURE 138. Directivity pattern, FM sonar transmitter in vertical plane making a +30° angle with acoustic axis at 34 kc.

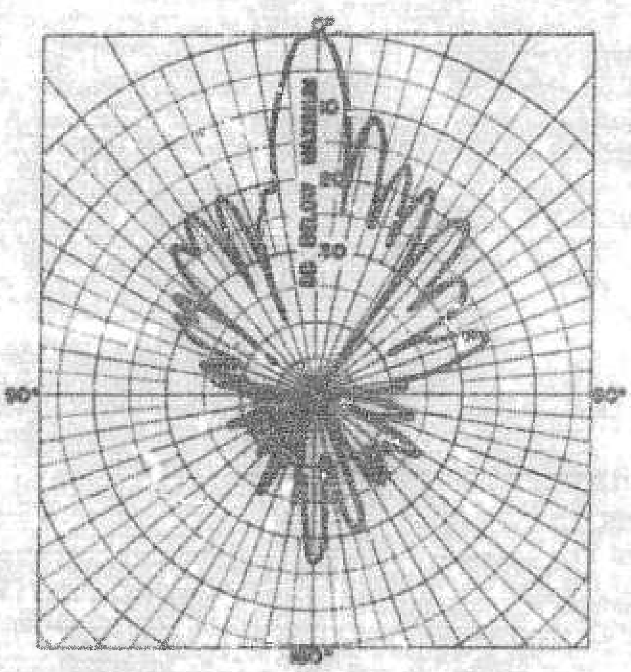

FIGURE 137. Directivity pattern, FM sonar transmitter in vertical plane through acoustic axis at 50 kc.

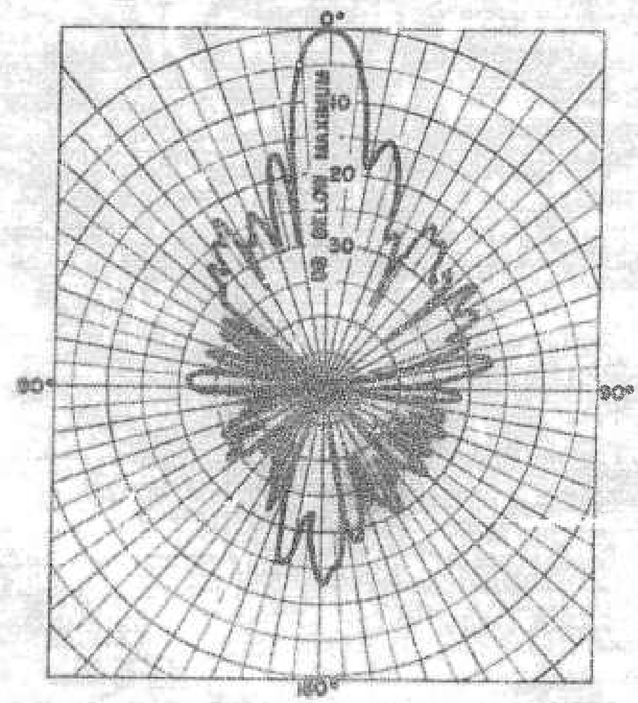

FIGURE 139. Directivity pattern, FM sonar transmitter in vertical plane making a +30° angle with acoustic axis at 42 kc.

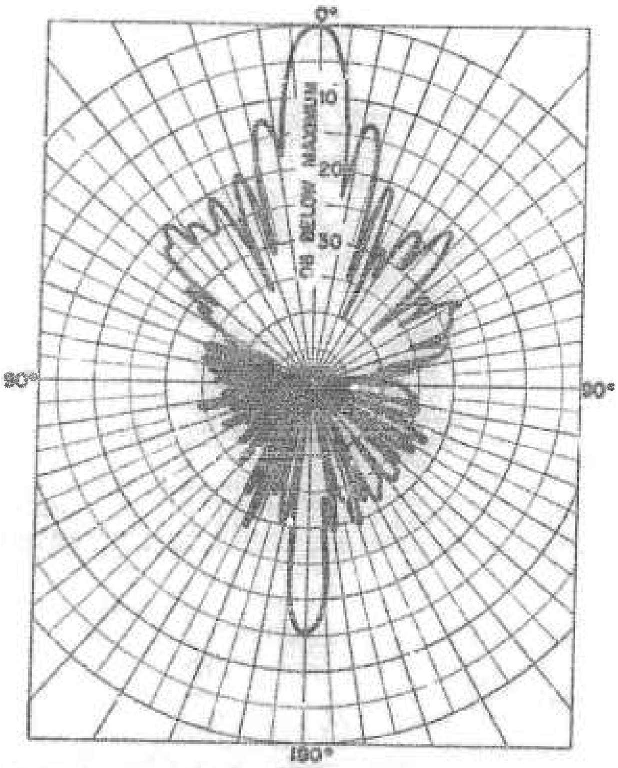

FIGURE 140. Directivity pattern, FM sonar transmitter in vertical plane making a +30° angle with acoustic axis at 50 kc.

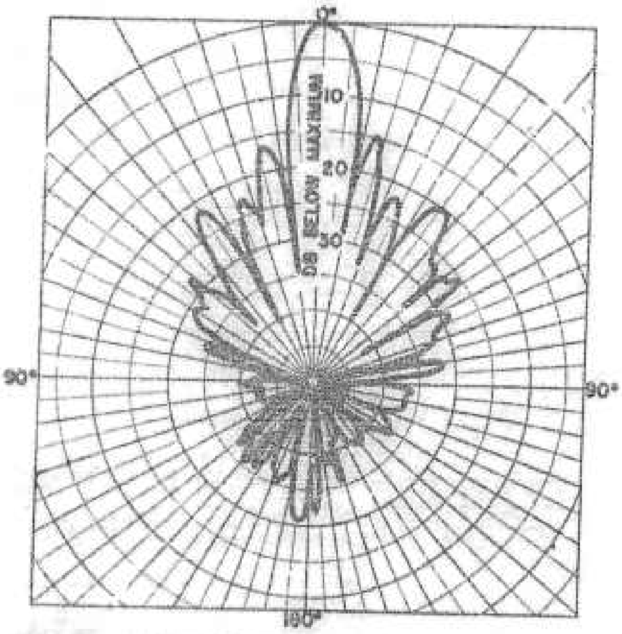

FIGURE 142. Directivity pattern, FM sonar transmitter in vertical plane making a —30° angle with acoustic axis at 42 kc.

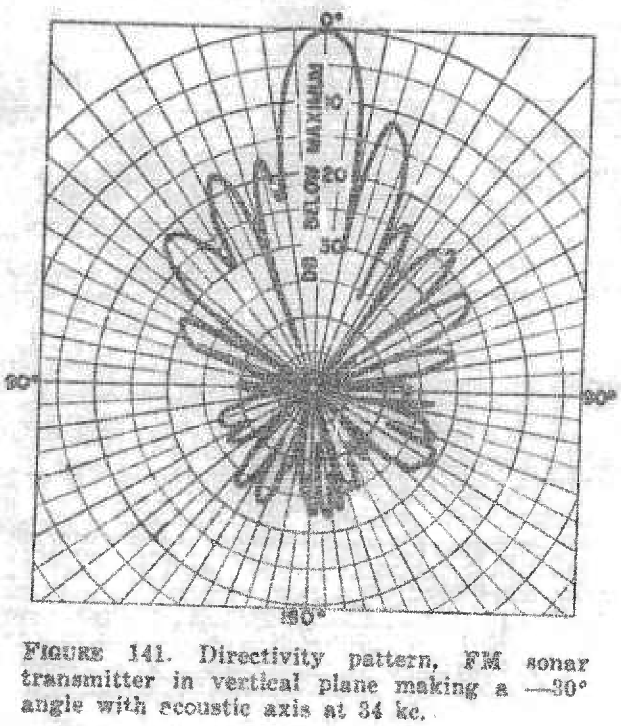

FIGURE 141. Directivity pattern, FM sonar transmitter in vertical plane making a —30° angle with acoustic axis at 34 kc.

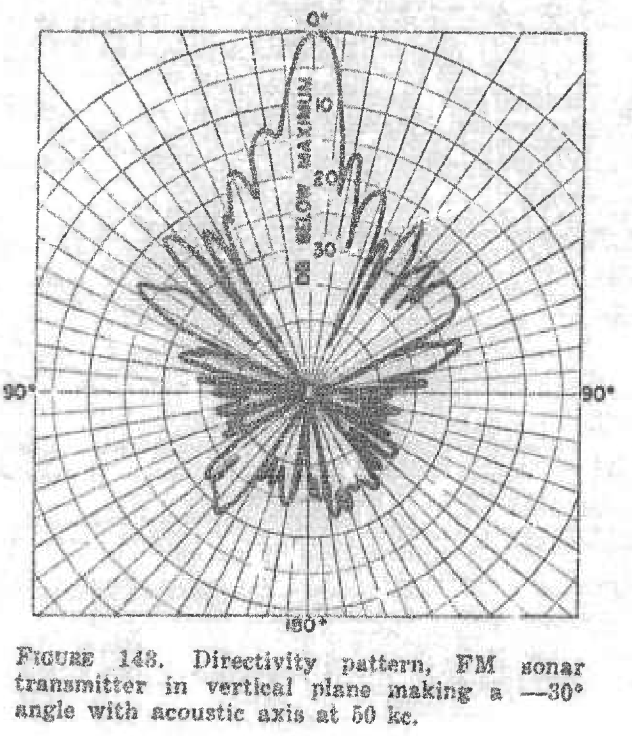

FIGURE 143. Directivity pattern, FM sonar transmitter in vertical plane making a —30° angle with acoustic axis at 50 kc.

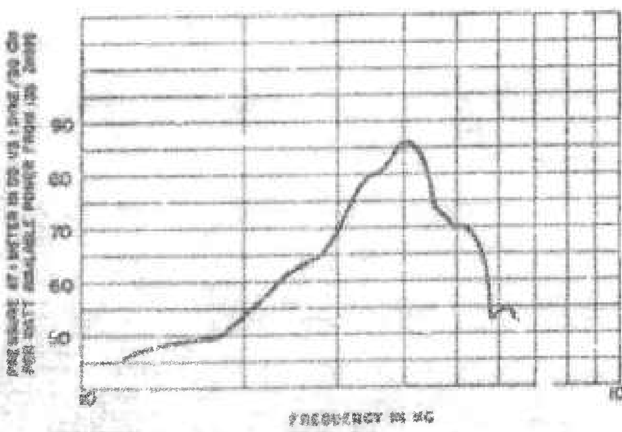

FIGURE 144. Transmitting response, transmitter unit of FM sonar.

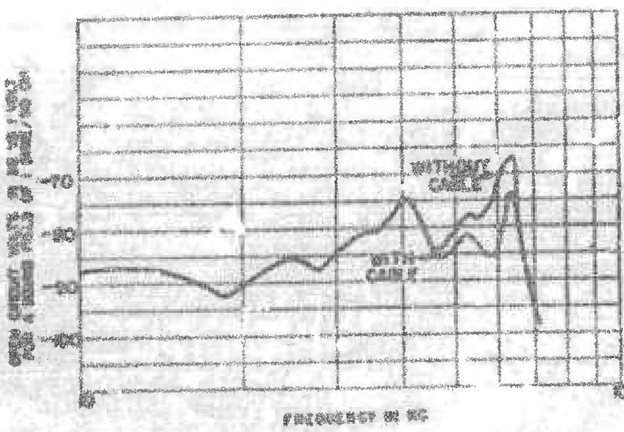

FIGURE 145. Receiving response, transmitter unit of FM sonar.

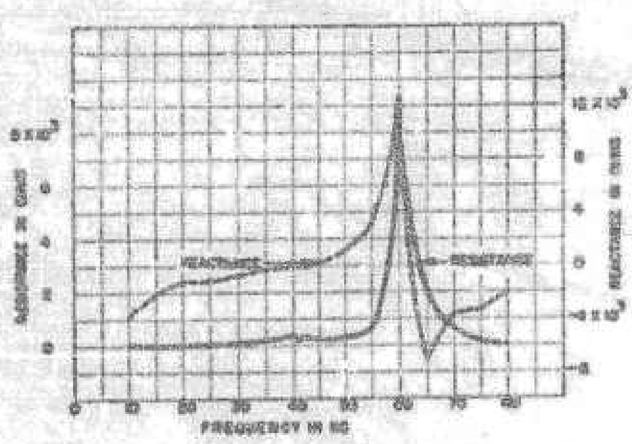

FIGURE 146. Impedance, FM sonar transmitting unit (without cable).

Calibration of Receiver.

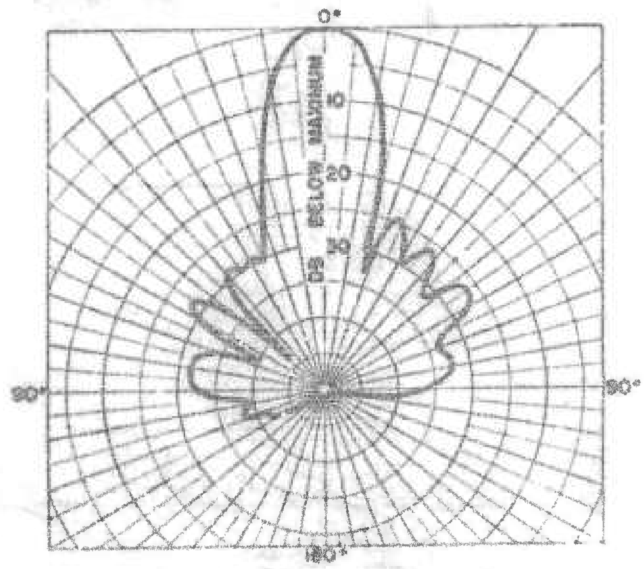

FIGURE 147. Directivity pattern, FM sonar receiver in horizontal plane at 34 kc.

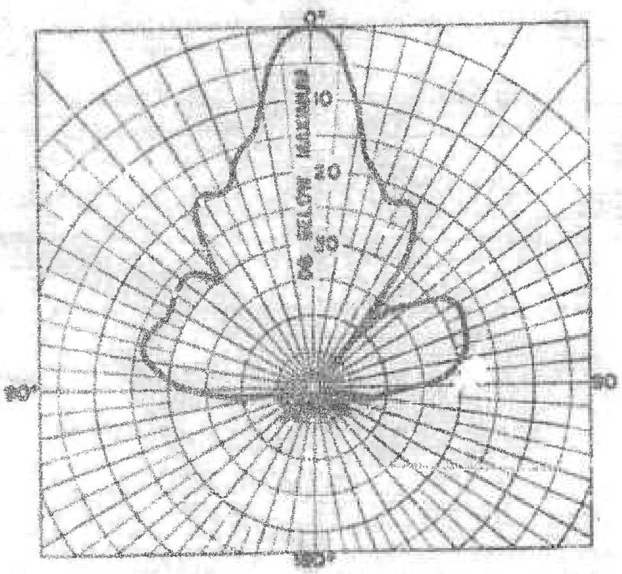

FIGURE 148. Directivity pattern, FM sonar receiver in horizontal plane at 42 kc.

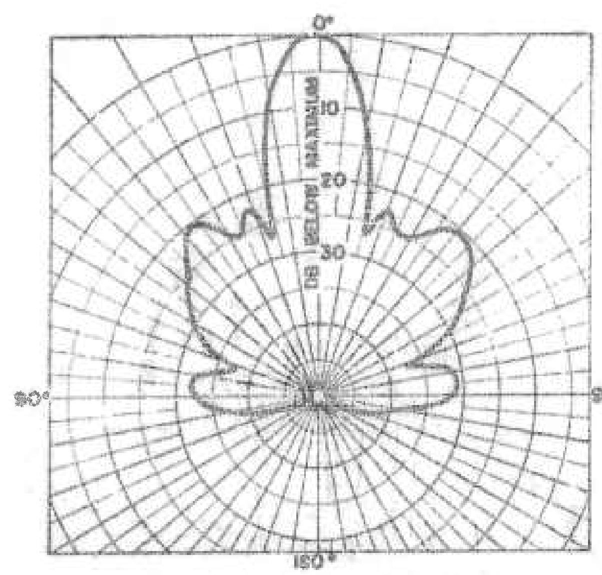

FIGURE 149. Directivity pattern, FM sonar receiver in horizontal plane at 50 kc.

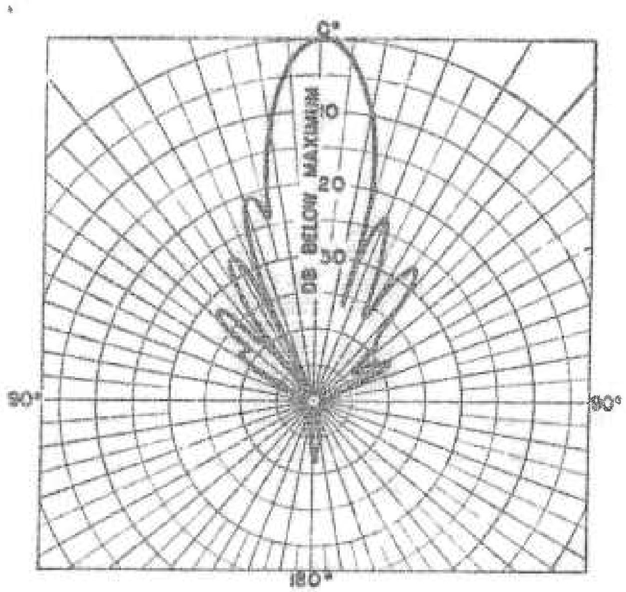

FIGURE 151. Directivity pattern, FM sonar receiver in vertical plane at 42 kc.

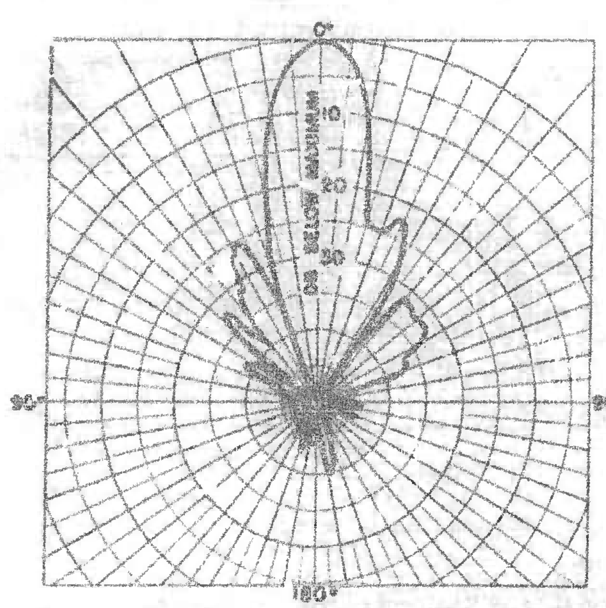

FIGURE 150. Directivity pattern, FM sonar receiver in vertical plane at 34 kc.

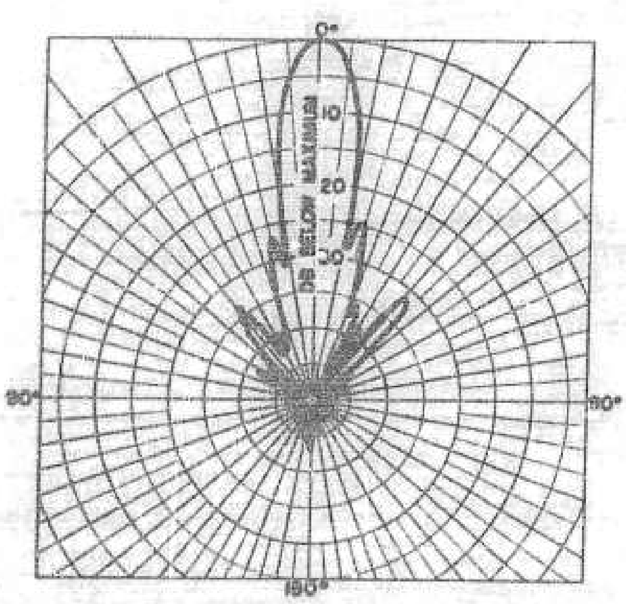

FIGURE 152. Directivity pattern, FM sonar receiver in vertical plane at 50 kc.

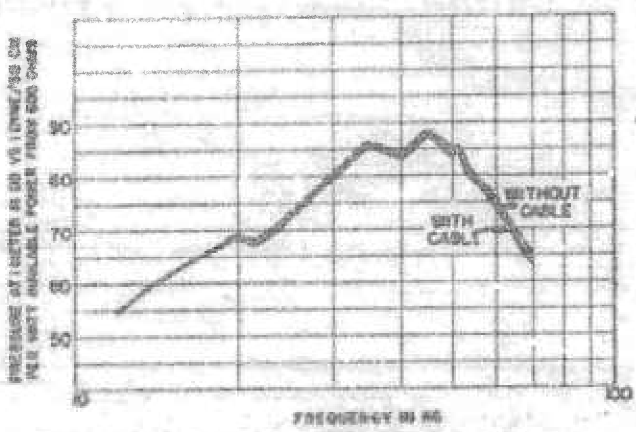

FIGURE 153. Transmitting response, FM sonar receiver.

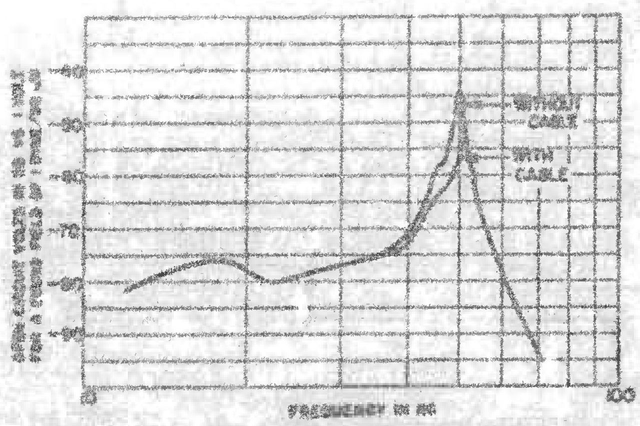

FIGURE 154. Receiving response, FM sonar receiver.

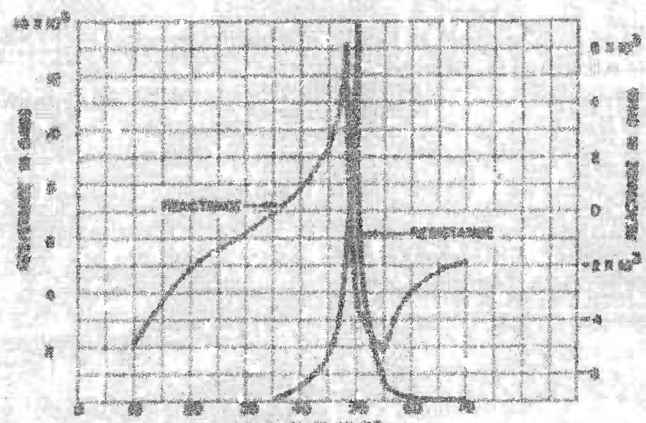

FIGURE 155. Impedance, FM sonar receiving unit (without cable).

6.8.4 Relation of Operational Effectiveness of Scanning Sonar in A/S Operations to Its Physical Characteristics[f]

The general principles relating the operational effectiveness of underwater sound devices to their physical design parameters, e.g., directivity and acoustic power output, have been discussed in detail.[138] From these discussions it follows that for ease of analysis the A/S operation is first divided into three parts (treated in inverse chronological order): attack, chase, detection.

In the attack the criteria of operational effectiveness are the values of the blind time and of the depth error, in the chase the value of the bearing accuracy and the ability to maintain contact, and in detection (in "searching" or "shielding") the values of the coverage rate and of the maximum range[g] at which contact can first be made.[138]

In the attack, both for scanning sonar as well as for searchlight gear, auxiliary close contact maintenance and depth determining equipment are necessary. Such auxiliary gear must satisfy the conflicting requirements of a short blind time and of an ability to measure depth with small errors, with reasonably long range. Assuming for the moment that scanning in the vertical plane is used, short blind times and small depth errors imply requirements on the vertical beam width and on the accuracy of bearing measurements on the PPI screen representing the vertical plane.

In the chase, maintenance of contact depends on the vertical beam width. Regarding bearing accuracy during the chase, tests performed by

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[f] This is with particular reference to the XQHA CR system in comparison with present searchlight gear and with searchlight gear incorporating certain improvements.

[g] The maximum range is defined as that range at which the probability of detecting an echo from a submarine against the background is just 50 per cent; the coverage rate is defined as the equivalent area swept by the A/S ship per unit time in which there is certainty of detecting the submarine. The search efficiency e_s, commonly adduced along with the maximum range r_{max} as a criterion of operational effectiveness in "shielding," can be expressed in terms of the coverage rate C and the maximum range by the equation $e_s = C/2r_{max}v$ (v is the relative ship-sub speed).

the USRL[161] indicate that visual observation on the PPI oscilloscope screen of the scanning sonar leads to bearing accuracies ≈ 1 degree, i.e., bearing accuracies of the same order as are obtained with BDI attachment to the scanning sonar. This bearing accuracy is obtained on the PPI screen giving horizontal bearings, but presumably comparable accuracy may be obtained on the PPI screen giving vertical bearings. Contact maintenance for a given vertical beam width is, of course, better with scanning sonar than with searchlight gear because of the 360° horizontal beam and the greater psychological certainty of visual presentation on the PPI screen; further, if the vertical beam is chosen as a reasonable compromise between the conflicting demands of contact maintenance during chase and attack and those of small depth error, or if an auxiliary broad vertical beam[h] and an auxiliary narrow beam "sword" projector is used, both depth errors and blind times may be made sufficiently small. Thus it is seen that, regarding blind time, depth error, and bearing accuracy, scanning sonar with necessary auxiliary equipment is at least equal in performance to searchlight gear, while with respect to contact maintenance, scanning sonar, because of the PPI visual presentation feature, is greatly to be preferred to the searchlight type of equipment.

Regarding detection, it is convenient first to estimate maximum ranges which may be obtained under comparable oceanographic conditions with scanning sonar and with searchlight gear. The pressure output at 1 m of XQHA scanning sonar is approximately 115 db vs 1 dyne per sq cm,[161] some 4 db higher than that of present searchlight gear (QBF, QCU, etc.). See Chapter 2. The background in the scanning sonar, as far as noise (largely self-noise) is concerned, is equivalent to the level in a band of approximately 2 kc (see Figure 125). Also for visual recognition on the PPI screen, the signal level must exceed that of the noise by some 5 db for 50 per cent recognition; this value for the 50 per cent visual recognition differential on the PPI screen was found in detailed visual recognition tests conducted by the USRL.[168] On the other hand, the 100-msec ping signal, commonly used in searchlight systems with aural recognition,[i] can be recognized at a level some 10 db below a 2-kc noise background (50 per cent aural recognition differential of —7 db with respect to noise in a 1-kc band).[158]

Further, the receiving beam has a directivity index ≈ —28 db for scanning sonar[161] and ≈ —23 db for searchlight gear (see Chapter 2); thus the effective noise background is ≈ [5—(—10)]—5 = 10 db higher for scanning sonar than for present searchlight gear. Again the reverberation level will tend to be higher in scanning sonar than in present searchlight gear, because of the higher signal output (4 db), and it will tend to be lower because of the shorter ping used, 30 rather than 100 msec (5 db), and the narrower receiving beam (5 db). Moreover the 50 per cent PPI visual recognition differential versus reverberation is probably greater than that against noise (because of the greater "peakiness" of reverberation)—it may be taken as ≈ 7 db; on the other hand, the 50 per cent aural recognition differential versus reverberation is ≈ 8 db.[158] Thus the effective reverberation background is 2 db lower in scanning sonar than in current searchlight gear. It is thus seen that under given oceanographic conditions and, of course, with the same frequency, i.e., the same transmission loss, the signal level is 4 db higher in scanning sonar than in present searchlight gear, the effective noise level is 10 db higher, and the effective reverberation level 2 db lower. As a result, noise limited ranges will be somewhat shorter (about 10 per cent) with scanning sonar than with present searchlight gear and reverberation limited ranges somewhat longer (about 15 per cent). Of course, with scanning sonar, ranges will remain noise limited up to

[h] A broad beam in the vertical plane required for close contact maintenance—short blind time may be obtained by using the output of a portion of the length of the cylindrical transducer.

[i] The values of both the visual and the aural recognition differentials used are obtained from tests wherein undistorted signals are injected into a thermal noise background. Actual signal distortion and a "peakiness" greater than that found in thermal noise will adversely affect both visual and aural recognition. The quantitative measure of this adverse effect must await studies on recognition differential as a function of signal distortion and of noise "peakiness."

somewhat shorter distances from the echo-ranging vessel.

This analysis leads to the conclusion that comparable maximum detection ranges may be expected from scanning sonar and from present searchlight gear under all oceanographic conditions. This expectation is borne out by actual sea tests. It should be recalled, however, that

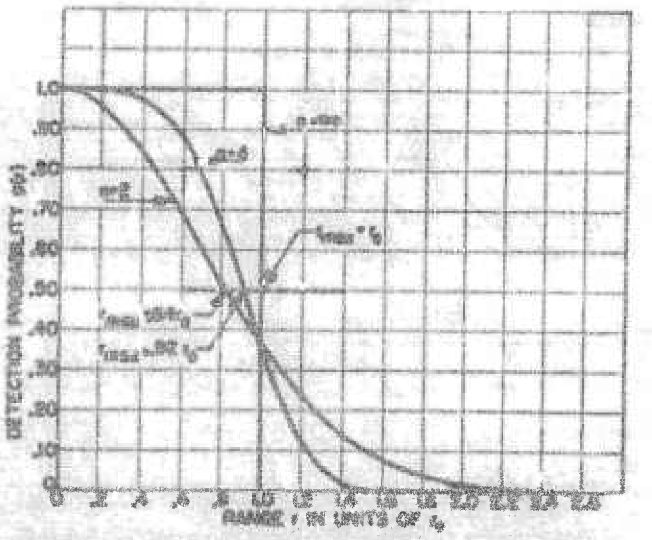

FIGURE 156. Detection probability as a function of range.

improvements have been suggested in searchlight gear, namely, the use of a lower frequency and a larger size projector with acoustic power output up to the resulting cavitation limit, which give maximum ranges roughly twice as large as present searchlight gear.

The coverage rate obtainable with scanning sonar for a given maximum range will, in general, be considerably greater than that obtainable with searchlight gear. This conclusion is a consequence of the simultaneous insonification by the scanning sonar beam of the whole 360° horizontal section resulting essentially in the detection of all targets within the maximum range; with searchlight gear, on the other hand, because of the relatively narrow beam and the time required to complete a full sweep, targets may not be detected even though within the maximum range.

Coverage rates that may be expected with scanning sonar are given in this section.[164] The coverage rate depends on the relative ship-sub velocity v, on the maximum range r_{max}, on the judged range r_j, i.e., on the interval T between successive pings, $(r_j = cT/2)$, and on the shape of the detection probability versus range curve. The latter is taken as (see Figure 156)

$$p(r) = e^{-(r/r_0)^n}; \quad n = 2, 4, \infty,$$

where $p(r)$ is the probability of detecting a sub at range r, and the constant r_0 is determined by the fact that

$$p(r_{max}) = 0.50,$$

that is, the probability of detection at the maximum range is just 50 per cent. In practice, the shape of the detection probability versus range curve is determined by the variation of both signal and background with range[j], i.e., mainly by attenuation conditions, and by a psychological curve relating the signal to background ratio and the probability of detection in per cent;[k] computations indicate that the curve in Figure 156 with $n = 4$ is in fair agreement with detection probability versus range curves obtained in practice.[l] The curves in Figure 156 with $n = 2$, $n = \infty$ represent extreme cases of a long "tail" and no "tail" at all for the detection probability; it is obvious that a long "tail"

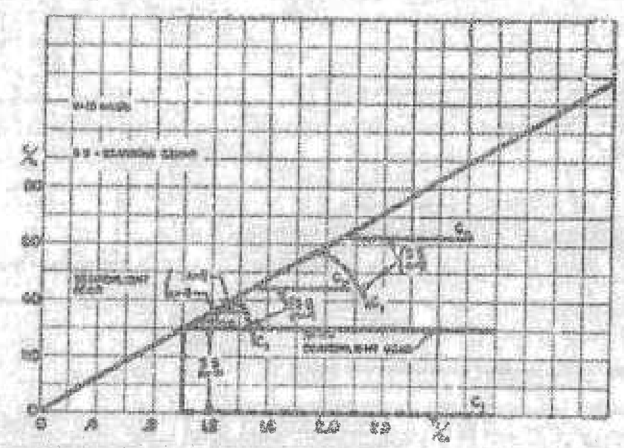

FIGURE 157. Coverage rate for scanning sonar and searchlight gear. Ship speed = 15 knots.

is useful in scanning sonar. This conclusion follows from the fact that in scanning sonar each target is pinged on a great many times because of the 360° beam and so may have a

[j] See Figure 20 of reference 153.

[k] See Figures of reference 164.

[l] Compare the curve with $n = 4$ in Figure 156 with the detection probability versus range curve given in Figure 20 of reference 153.

resultant probability of detection which is not negligible even though the probability of detection per ping is very small.

Figures 157 and 158 give coverage rates for

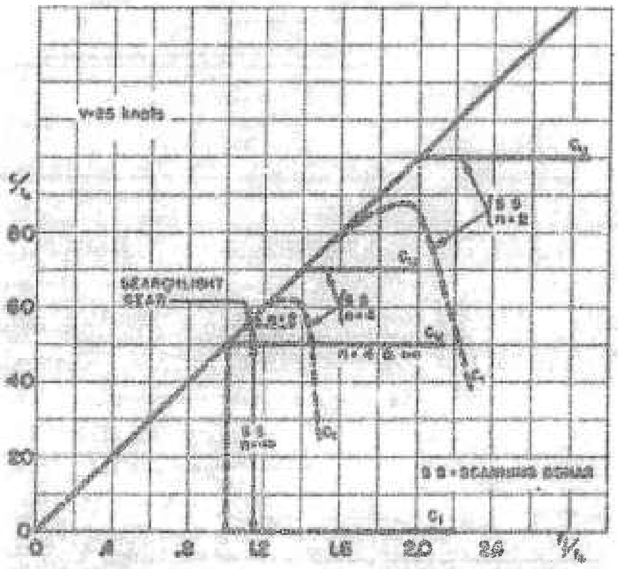

FIGURE 158. Coverage rate for scanning sonar and searchlight gear. Ship speed = 25 knots.

scanning sonar for ship-sub speeds of 15 knots and 25 knots as a function of r_j/r_{max} and for $n = 2, 4$, and ∞. The coverage rate C, and the search efficiency e_s, ($e_s = C/2r_{max}v$), obtained from these curves, using in each case the optimum value of the judged range,[m] are shown in Table 2.

TABLE 2

	15 knots			25 knots		
	$n = 2$	$n = 4$	$n = \infty$	$n = 2$	$n = 4$	$n = \infty$
C in square nautical miles per hour	$75r_{max}$	$50r_{max}$	$30r_{max}$	$125r_{max}$	$75r_{max}$	$50r_{max}$
e_s	250%	160%	100%	250%	150%	100%

In a similar way, the coverage rates of searchlight gear may be found. These coverage rates depend, in addition to the factors mentioned above, (r_j, r_{max}, n, v) on the beam width which, for all present and proposed searchlight gear, corresponds to a directivity index of about −23 db. Figures 157 and 158 also present coverage rates of searchlight gear for ship-sub speeds of 15 and 25 knots as a function of r_j/r_{max} and for $n = 2, 4, \infty$ (directivity index = −23 db). The coverage rate and search efficiency values obtained from these curves, using in each case the optimum value of r_j, are shown in Table 3.

TABLE 3

	15 knots			25 knots		
	$n = 2$	$n = 4$	$n = \infty$	$n = 2$	$n = 4$	$n = \infty$
C in square nautical miles per hour	$40r_{max}$	$35r_{max}$	$30r_{max}$	$65r_{max}$	$55r_{max}$	$50r_{max}$
e_s	135%	115%	100%	130%	110%	100%

If the maximum range is taken to be equal for scanning sonar and present searchlight gear, that is, ≅ 8,000 yd in good oceanographic conditions, it is seen that the scanning sonar has a somewhat higher coverage rate than present searchlight gear. On the other hand, with searchlight sonar gear incorporating proposed improvements[169] and expected to yield in good oceanographic conditions twice the above maximum range, the coverage rate values are twice those in Table 3. (The search efficiency values will be the same as in Table 3.)

Thus the proposed improved searchlight gear has a greater coverage rate except in the long "tail" case, $n = 2$, as well as a much greater maximum range than the scanning sonar. These advantages in detection may, however, be balanced by the advantages of scanning sonar in the chase and attack.

Conclusion

It is seen from the above discussion that in A/S operations, scanning sonar is superior to

[m] The optimum value of the judged range is, of course, the one which gives the greatest coverage rate for a given maximum range and ship-sub speed. See Figure 157.

all searchlight gear, present and proposed, in the chase and in the attack. In detection, scanning sonar is superior to present searchlight gear, but is possibly inferior to a proposed searchlight gear capable of a maximum range twice that obtainable at present.

Chapter 7

INDUSTRIAL DESIGNS

THE INSTRUMENTS DESIGNED or built by industrial organizations under contract with the Navy or NDRC are described in this chapter. In many cases instruments were both designed and manufactured by the same manufacturer, although some instruments were developed by NDRC laboratories and manufactured by industrial companies. As a rule only devices calibrated by the USRL have been included. Many devices which have been included in other chapters are merely referred to herein. The following organizations are covered in this chapter: Brush Development Company, Bell Telephone Laboratories, Submarine Signal Company, Radio Corporation of America, and General Electric Company. The QBG, manufactured by the Freed Radio Corporation, is discussed in Section 2.7.18, and the tourmaline gauges made by Stanolind Oil and Gas Company are covered in Section 6.7.3. The scanning sonar designed by Harvard University and manufactured by the Sangamo Electric Company is described in Section 6.8.2.

7.1 INSTRUMENTS DESIGNED AND MANUFACTURED BY BRUSH DEVELOPMENT COMPANY

All underwater acoustic instruments designed and manufactured by the Brush Development Company employ piezoelectric coupling. Most of them use X-cut Rochelle salt crystals, although some use ADP crystals, e.g., AX-128, AX-114A, and AX-50. Neither Rochelle salt nor ADP crystals has a volume piezoelectric effect of useful magnitude, that is, the open-circuit voltage is very small when the crystal is compressed in such a way as to change its volume. The volume is changed when a pressure acts on all faces of the crystal. In order to prevent the pressure from acting on all sides of the crystal, the pressure must be relieved on some faces. This is accomplished in most Brush designs by covering four sides of the crystal unit with Corprene. Of the other two sides, one usually is exposed as the active face and the other is covered by a mounting plate, but sometimes both sides are exposed in a double-face design (C10, C11).

As the impedance of crystal units is high, there is a large loss in the signal intensity of hydrophones when long leads are attached directly to the crystals (coupling loss), with consequent high electric noise and electric pickup. Several methods are used to reduce this loss and circuit noise. (1) Short leads from hydrophone to receiving equipment are used. This method, for example, is employed in the C49 and AX-47 hydrophones. (2) A transformer is built into the hydrophone to step down the output impedance of the crystal so as to permit long cables to be used with the hydrophone. Examples of this construction method are C23 and C37 hydrophones. (3) A one- or two-stage preamplifier is used near the hydrophone, i.e., underwater, permitting use of short leads from the crystal. The low output impedance of the preamplifier then minimizes coupling loss. Usually the preamplifier is built into the hydrophone. This is done in C50 and AX-75 units.

Some of the hydrophones intended for use as measurement standards, e.g., the C10, include calibrating circuits for obtaining the open-circuit crystal response.

Almost all the instruments are filled with castor oil to permit their use at depths of several hundred feet without collapse and to withstand explosion shocks. Most of them are completely enclosed in sound-transparent rubber, or at least the active face is rubber-covered. Important exceptions in both respects are the C10 and C11 hydrophones which are neither oil-filled nor rubber-covered. These hydrophones, being intended for use as standards, are intended neither for use at considerable depth nor to be exposed to explosions.

Various combinations and arrangements of crystal units have been employed to give particular directivity patterns. Line hydrophones, such as the C37, which are nondirectional in a plane normal to the line and discriminate

against sounds originating in a direction along the line, consist of several crystal units arranged in a row and connected electrically in parallel. Nondirectional units, like the AX-79, consist of a single crystal unit. Dual-pattern hydrophones (C44, AX-6, AX-47) are essentially two hydrophones in one housing, one being directional and the other nondirectional. By connecting these two units opposing a differential hydrophone may then be obtained. Other special pattern devices have also been built.

Any instrument which does not have a built-in preamplifier can be used as either a projector or a hydrophone. Both response curves are given here in many such cases, although the device is intended mainly for one or the other of these roles. Other units are intended only for transmitting sound, e.g., the AX-63 projector.

Many preliminary and experimental models are mentioned in the descriptions of the final instrument. Several Brush designs have been used by the USRL as standards, for example, the C11, C13, AX-91, and AX-124 units. A description of these devices will be found in Sections 1.4.17, 1.4.8, 1.4.13, and 1.4.2, respectively. The JO, JQ, Modified JQ, and AX-58 are to be found in Sections 2.7.2, 2.7.4, 2.7.5, and 2.7.40, respectively. References to calibrations of Brush instruments in this chapter are to be found in Sections 7.6.1 to 7.6.16.

7.8 INSTRUMENTS DESIGNED AND MANUFACTURED BY BELL TELEPHONE LABORATORIES

The work of the Bell Telephone Laboratories [BTL] in this war has been concerned with many aspects of the underwater sound field, as covered by contracts with both NDRC and the Navy. As discussed in Chapter 1, BTL have designed and constructed the majority of the standard hydrophones and projectors which have been used by the USRL and by other laboratories working in the field. The BTL built most of the electrical equipment for the USRL test stations.[a] They designed Navy echo-ranging equipments, such as the QBF and the QJB systems, which were manufactured by the Western Electric Company for the Navy, and constructed various ordnance devices and experimental sonar apparatus. In addition, they carried out a number of investigations in the underwater sound acoustical field. For instance, they made a study of listening systems for patrol craft, for which they developed various instrumentalities as well as acoustical designs.

[a] See STR Division 6, Volume 10.

The USRL have assisted in many phases of this work through the calibration of devices but have by no means had contact with all of the activity of the BTL. Several of the Navy equipments developed by BTL are described in Chapter 2. In Sections 7.6.17 to 7.6.22 are given descriptions of a number of listening devices designed by BTL, such as the 4A, 5A, 7A, 8A, and 9A hydrophones, and a nondirectional magnetostriction hydrophone. In addition, there are described three projectors designed by BTL for the University of California, Division of War Research, at San Diego, for use in underwater sound transmission studies. (See Section 7.6.23.)

7.9 INSTRUMENTS DESIGNED AND MANUFACTURED BY SUBMARINE SIGNAL COMPANY

The Submarine Signal Company [SSC] has a leading role in the production of underwater sound equipments for the U. S. Navy. The USRL has calibrated a number of transducers designed and manufactured by SSC for underwater use.

Twenty-five of these transducers are described in Chapter 2. Of this number, 5 are magnetostrictive types used in echo-sounding equipment, 17 are used in echo-ranging equipment, of which 7 are the magnetostrictive type, 3 use Rochelle salt crystals for the active elements, and 7 are a combination of a magnetostriction unit and a Rochelle salt crystal unit, mounted back to back in the same housing. Three of the transducers tested are experimental units. One of these uses ADP crystals for its electroacoustic coupling, one is an electrodynamic type, and one consists of a magnetostrictive type unit in a reflector-type housing.

In addition to the transducers described in Chapter 2, the USRL calibrated two line hydrophones. The SS-6 is a 6-ft line and the S-124 is a 2-ft line. These hydrophones are described in Sections 7.6.25 and 7.6.24 respectively.

7.4 INSTRUMENTS DESIGNED AND MANUFACTURED BY THE RADIO CORPORATION OF AMERICA

The instruments designed by The Radio Corporation of America [RCA] and tested by the USRL have employed all types of electroacoustic coupling. The Electrodynamic hydrophone (see Section 7.6.27), as the name implies, is an electromagnetic device. The Magnetostriction hydrophone (see Section 7.6.28) uses a magnetostrictive nickel rod as active element. The 2A Condenser hydrophone (see Section 7.6.26) employs electrostatic coupling. The USDAR (see Section 7.6.29) uses piezoelectric quartz crystal. All these types have worked satisfactorily, although the condenser type has not been widely used. The USDAR has been manufactured in large quantities, but the other three were mainly experimental and preliminary models. Other magnetostrictive and piezoelectric instruments have been manufactured by RCA in large quantities for Navy use and are discussed in Chapter 2.

7.5 INSTRUMENTS DESIGNED AND MANUFACTURED BY THE GENERAL ELECTRIC COMPANY

Two types of General Electric Company [GE] instruments have been calibrated by the USRL (see Sections 7.6.30 and 7.6.31). The Carbon hydrophone, an early type adapted from the carbon air microphone was intended for use in a binaural listening system. Much later several high-frequency projectors used with the Underwater Object Locator were tested. These units employed L-cut Rochelle salt crystals and, due to the high frequencies (250, 750 kc) at which they operate, could be mounted on curved plates to obtain desired directivity patterns.

Submarine Signal Company Projectors Discussed in Chapter 2.

Section	U. S. Navy No.	SSC No.	Type	Use
2. 7. 10	CBM 78016A	551B	M/S	Sounding
2. 7. 19	CBM 78017	550C	M/S	Echo ranging
2. 7. 9	CBM 78067	763	M/S	Sounding
2. 7. 20	CBM 78099	550L	M/S	Echo ranging
2. 7. 24	CBM 78115	733F	M/S-R/S	Echo ranging—listening
2. 7. 8	CBM 78138	713C	M/S	Sounding
2. 7. 15	CBM 78142	865	R/S	Echo ranging—listening
2. 7. 16	CBM 78142A	865A	R/S	" "
2. 7. 27	CBM 78145	880	M/S	" "
2. 7. 34	CBM 78153	733H	M/S-R/S	" "
2. 7. 38	CBM 78156	885	M/S-R/S	" "
2. 7. 28	CBM 78164A	900E	M/S-R/S	" "
2. 7. 23	CBM 78182	550V	M/S	" "
2. 7. 21	CBM 78183	550W	M/S	" "
2. 7. 25	CBM 78184	733K	M/S-R/S	" "
2. 7. 26	CBM 78185	733L	M/S-R/S	" "
2. 7. 13	CBM 78203	943	M/S	Sounding
2. 7. 35	CBM 78212	948	M/S-R/S	Echo ranging—listening
2. 7. 36	CBM 78213	733R	R/S	Echo ranging
2. 7. 14	CBM 78214	947	M/S	Sounding
2. 7. 30	CBM 78220	941	M/S	Echo ranging
2. 7. 31	CBM 78221	942	M/S	"
2. 7. 44	....	SK 5982	ADP	Experimental
2. 7. 48	....	SK 4044	Electrodynamic	"
2. 7. 49	....	SK 4610C	M/S-reflector	"

7.6 INDUSTRIAL DESIGN INSTRUMENTS

7.6.1 AX-47 and AX-47-1 Hydrophones

Type: X-Cut Rochelle Salt Crystal.

Designer and Manufacturer: Brush Development Company.

Reference: NDRC Report No. 6.1-sr20-610, March 9, 1943.[193]

Description: Both the AX-47 and AX-47-1 models contain a directional unit consisting of a circular crystal array and a centrally located nondirectional crystal unit. A schematic diagram giving the approximate dimensions of the AX-47 hydrophone is shown in Figure 4. The AX-47-1 model is similar to the AX-47. The operation is similar to that of the C44 described in Section 7.6.14.

Impedance in ohms:

Frequency (kc)	Directional unit R X	Nondirectional unit R X
10.0	30,900 — j317,000	20,100 — j317,000
20.0	39,900 — j187,000	29,500 — j154,000
22.5	27,600 — j111,200	21,500 — j135,200
25.0	36,200 — j 91,600	25,500 — j 99,600
30.0	48,000 — j 52,600	42,400 — j 71,000
40.0	109,000 — j 32,400	81,200 — j 27,600
50.0	106,200 — j109,500	187,000 — j 78,200

Threshold in db vs 1 dyne per sq cm:

Frequency (kc)	Directional unit	Nondirectional unit
10	—81.6	—72.8
20	—79.1	—65.1
25	—82.9	—70.9
25	—81.3	—75.0
30	—86.0	—73.6
40	—81.1	—74.7
50	—79.6	—74.1

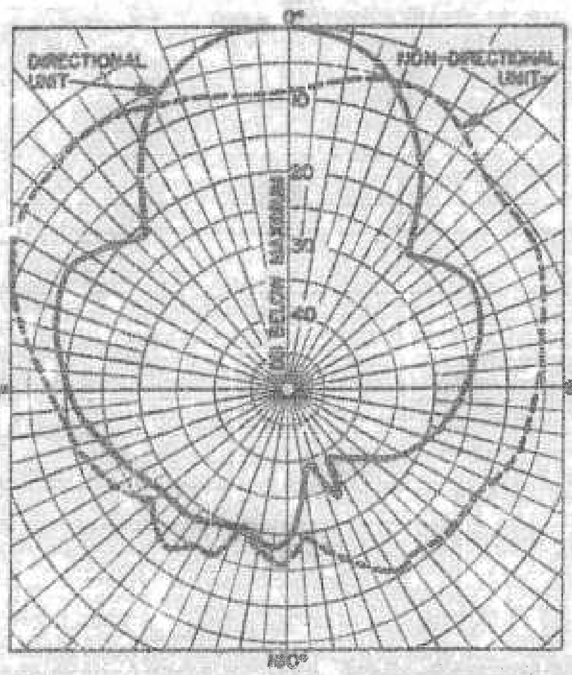

FIGURE 1. Directivity pattern, AX-47 hydrophone at 20 kc, response of nondirectional unit reduced 5 db below that of directional unit.

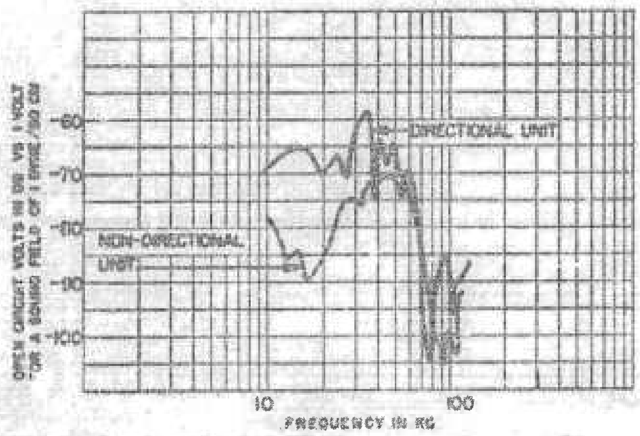

FIGURE 2. Receiving response, AX-47 hydrophone measured at output of coupling transformer.

FIGURE 3. AX-47 hydrophone with diaphragm removed.

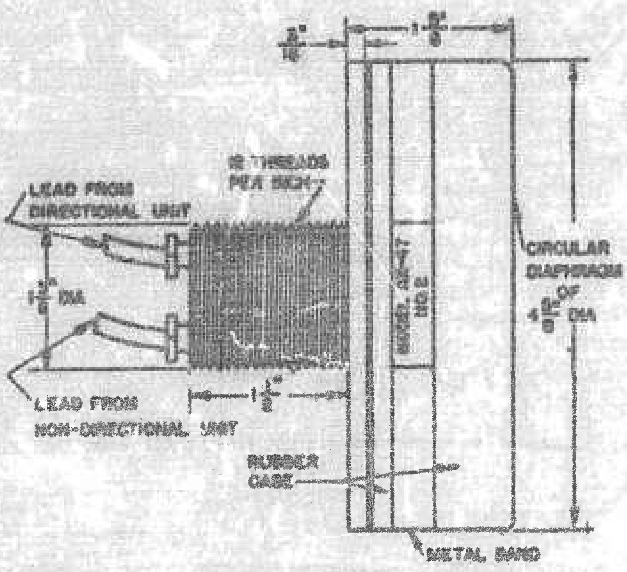

FIGURE 4. Dimensional drawing, AX-47 hydrophone.

7.6.2 AX-50 Hydrophone

Type: ADP Crystal.

Designer and Manufacturer: Brush Development Company.

Reference: NDRC Report No. 6.1-sr20-1181, October 22, 1943.[203]

Use: Listening unit intended for sono buoy.

Description: The ADP crystal is mounted in a rubber-covered, oil-filled, cylindrical housing similar to that of the C2?, C50, and other Brush models. The unit contains a built-in one-stage preamplifier which uses a 1LN5 tube (see circuit schematic diagram). The device is nondirectional from 1 kc up to about 30 kc.

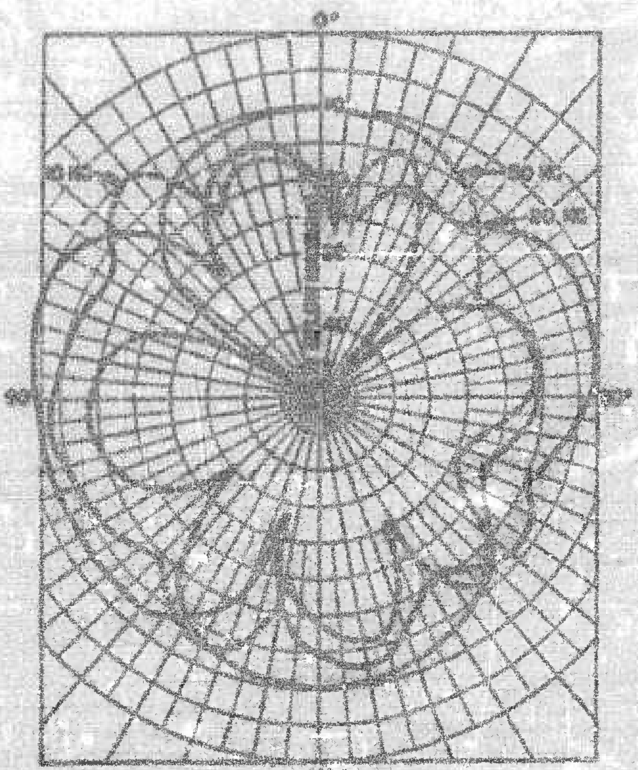

FIGURE 5. Directivity patterns, AX-50 hydrophone in plane containing long axis.

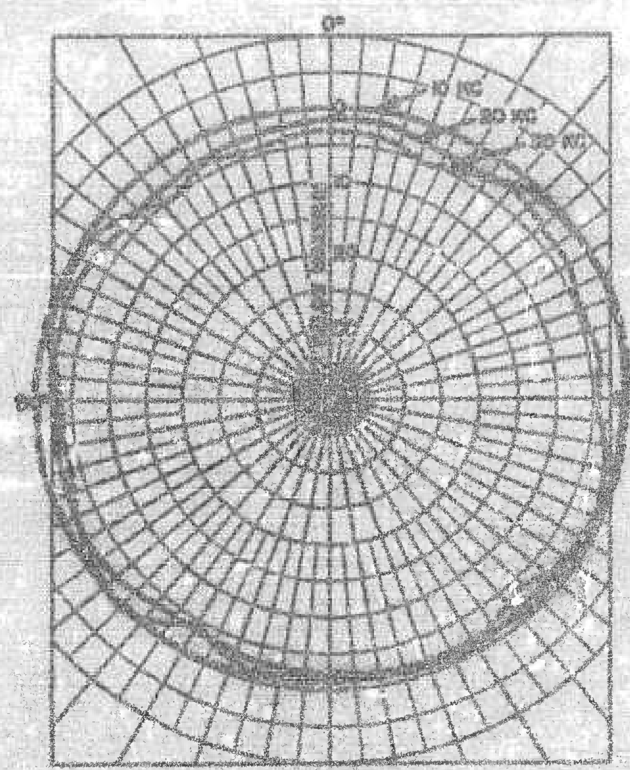

FIGURE 6. Directivity patterns, AX-50 hydrophone in plane normal to long axis.

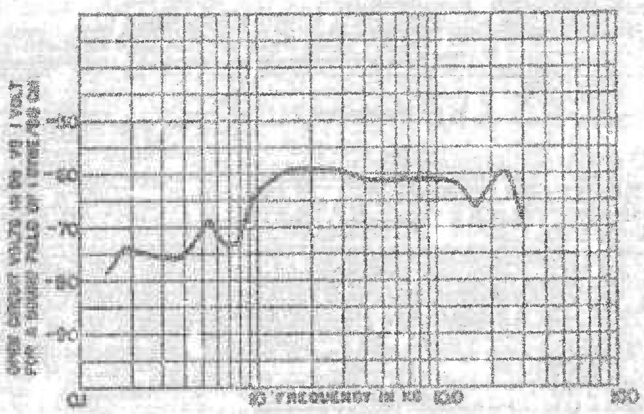

FIGURE 7. Receiving response, AX-50 hydrophone.

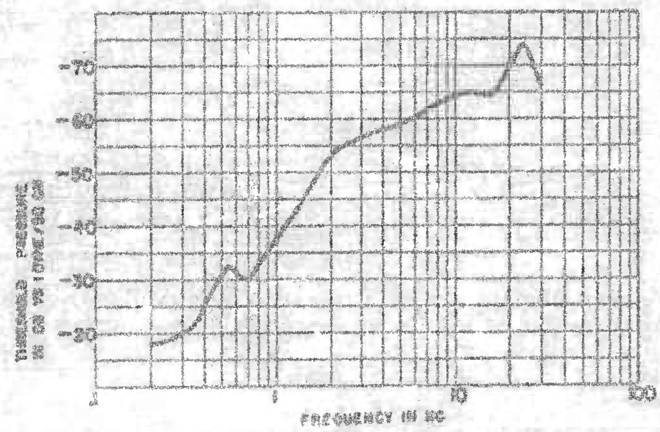

FIGURE 8. Measured threshold, AX-50 hydrophone.

FIGURE 9. AX-50 hydrophone.

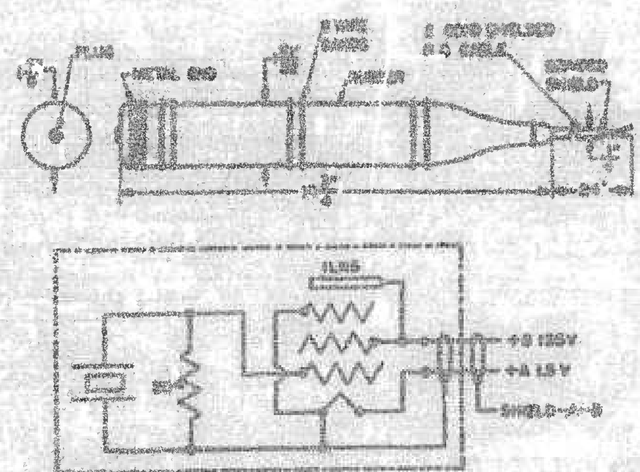

FIGURE 10. Dimensional drawing, AX-50 hydrophone and preamplifier circuit.

7.4.3 AX-58A (RQ-51055) Hydrophone

Type: X-Cut Rochelle Salt Crystal.

Designer and Manufacturer: Brush Development Company.

Reference: NDRC Report No. 6.1-sr20-949, August 17, 1943.[202]

Use: With portable measuring equipment.

Description: The AX-58A is a slight modification of the AX-58 which it replaces. It is similar in appearance to the C5C. The photograph shows the unit with the rubber cover removed.

It is approximately 26 in. in length and 2.5 in. in diameter. A 3-in. crystal block is mounted at one end and surrounded by a sound window. At the other end there is space for two stages of amplification which is to be furnished by the user. This instrument was widely used by the Navy in portable measuring equipment, especially for measuring and monitoring submarine noise output.

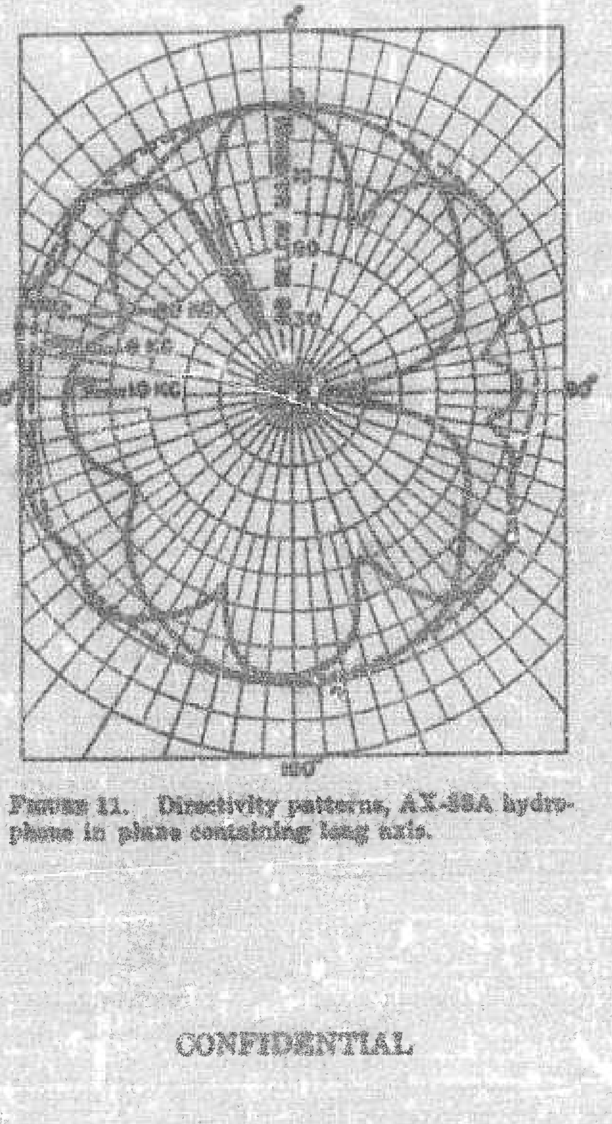

FIGURE 11. Directivity patterns, AX-58A hydrophone in plane containing long axis.

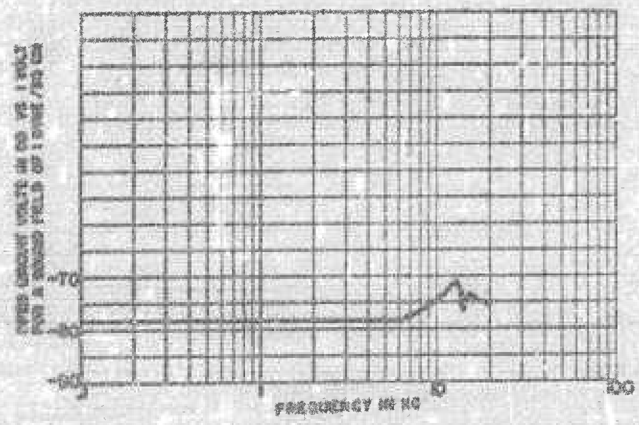

FIGURE 12. Receiving response, AX-58A hydrophone.

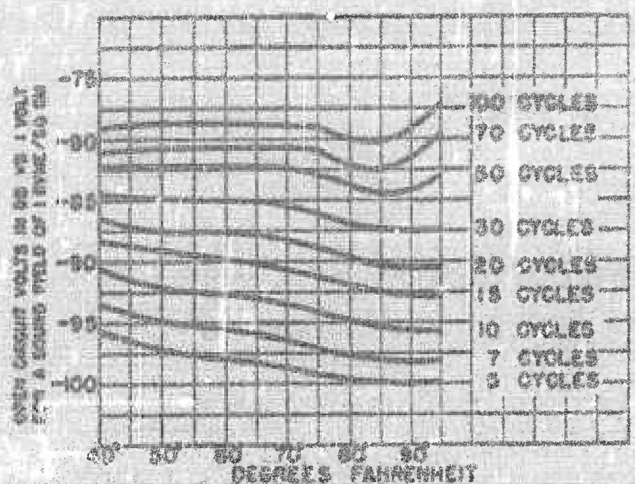

FIGURE 13. Temperature variation of receiving response, AX-58A hydrophone.

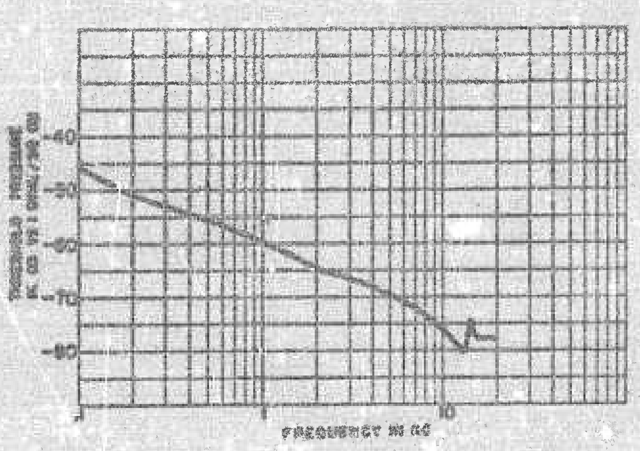

FIGURE 14. Measured threshold, AX-58A hydrophone.

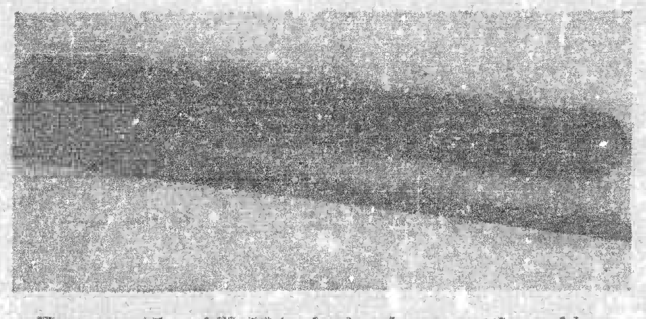

FIGURE 15. AX-58A hydrophone with rubber cover removed.

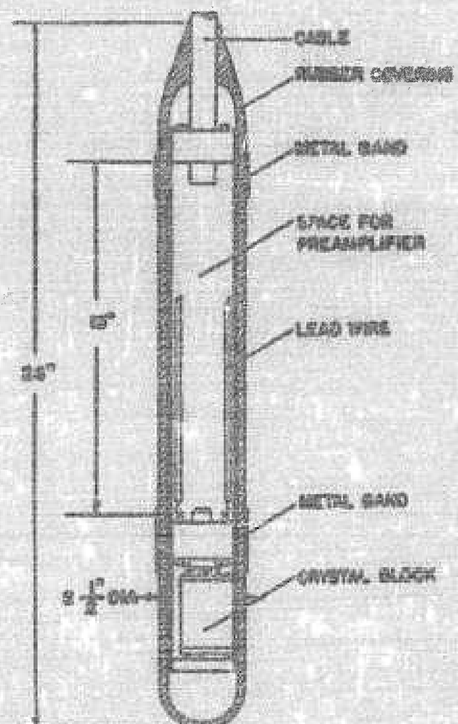

FIGURE 16. Dimensional drawing, AX-58A hydrophone.

7.4.4 AX-63 Projector

Type: ADP Crystal.

Designer and Manufacturer: Brush Development Company.

Reference: NDRC Report No. 6.1-sr1130-1187, November 16, 1943.[58]

Use: Echo ranging (experimental model).

Description: The instrument is cylindrical in shape, 14 in. in diameter and 5 in. in length. The crystals, ADP, are mounted on a glass plate. A ⅝-in. thick rubber diaphragm forms the front face and the space between the diaphragm and crystal block is oil-filled. The measurements were made at the terminals of a 20-ft cable attached to the instrument.

Impedance in ohms:

Frequency (kc)	Parallel tuning	Series tuning
23.0	4970 — j967	151 — j983
24.2	4750 — j1085	202 — j963
25.0	5080 — j1015	170 — j987

Threshold in db vs 1 dyne per sq cm:

Frequency (kc)	Parallel tuning	Series tuning
23.0	—87.0	—101.4
24.2	—89.9	—103.6
25.0	—88.5	—101.7

Transmitting Efficiency: Approximately —2 db at resonance.

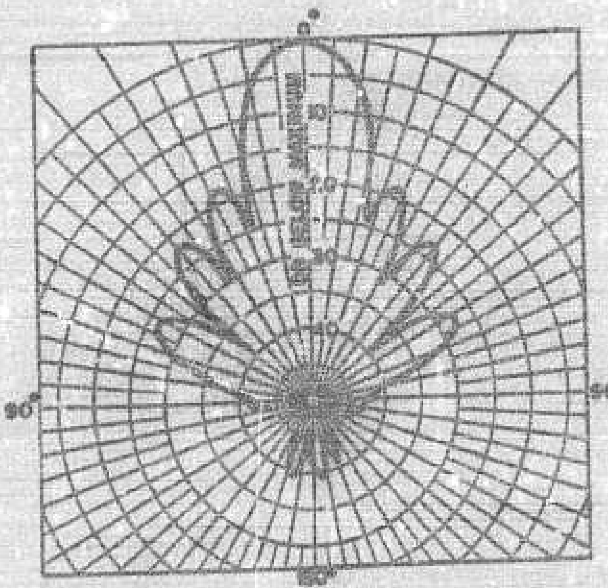

Figure 17. Directivity pattern, AX-63 projector at 24.2 kc.

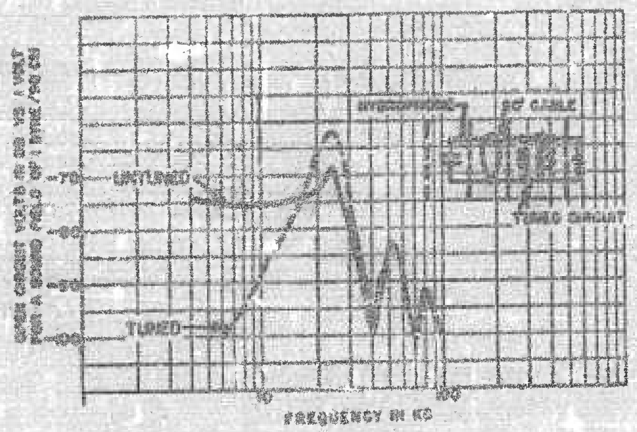

Figure 19. Receiving response, AX-63 projector

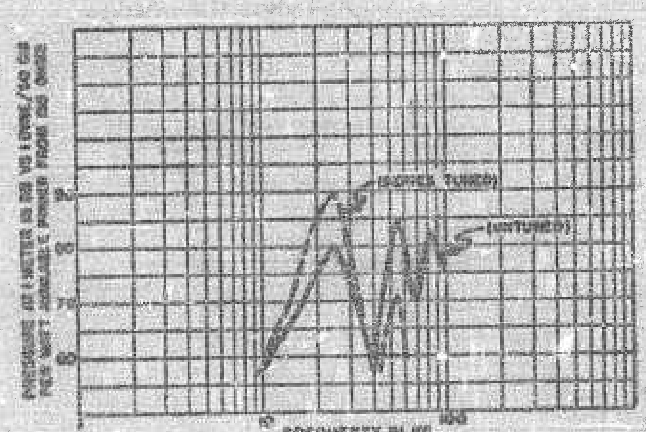

Figure 18. Transmitting response, AX-63 projector.

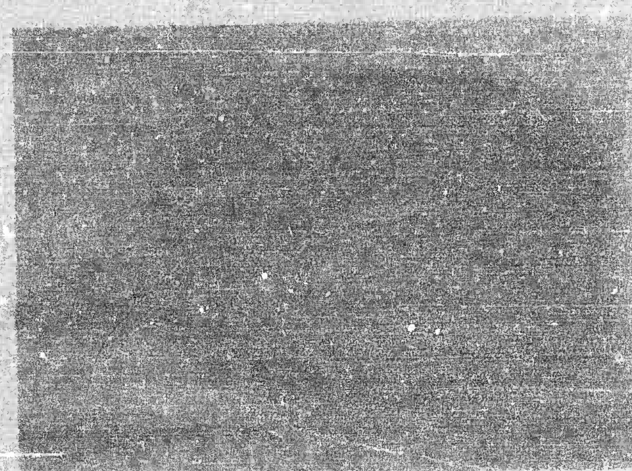

Figure 20. AX-63 projector.

7.6.8 AX-79, AX-79-1 Hydrophones

Type: X-Cut Rochelle Salt Crystal.

Designer and Manufacturer: Brush Development Company.

Use: Intended as sound pressure indicator inside a tank.

Description: The AX-79 and AX-79-1 are similar in construction and appearance but AX-79-1 is the slightly larger of the two, being about 6 in. long while AX-79 is only 4 in. long. Other dimensions are in proportion to the length. The crystals are cemented to a backing plate and enclosed in a sound-transparent rubber cover. The space between rubber and crystals is oil-filled. The housing incorporates a mounting flange to permit attachment to a tank. The unit is fairly nondirectional up to about 28 kc.

Efficiency: —3.5 db (for 150-db available power) at 26 kc.

Threshold: —91.4 db vs 1 dyne per sq cm at 26 kc.

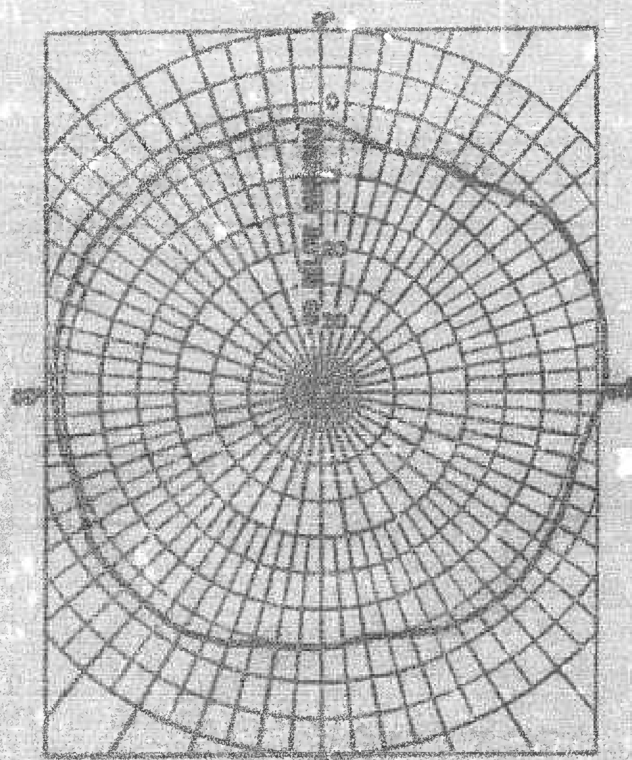

FIGURE 21. Directivity pattern, AX-79-1 transducer in plane containing short axis.

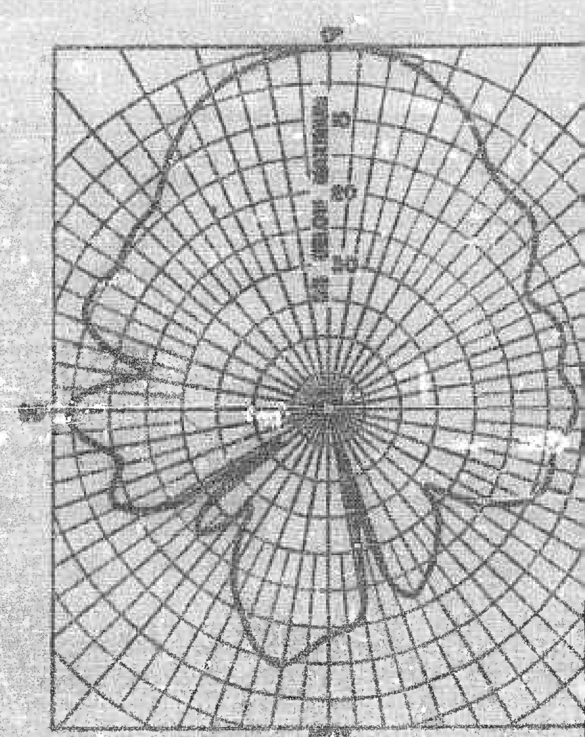

FIGURE 22. Directivity pattern, AX-79-1 transducer in plane containing long axis.

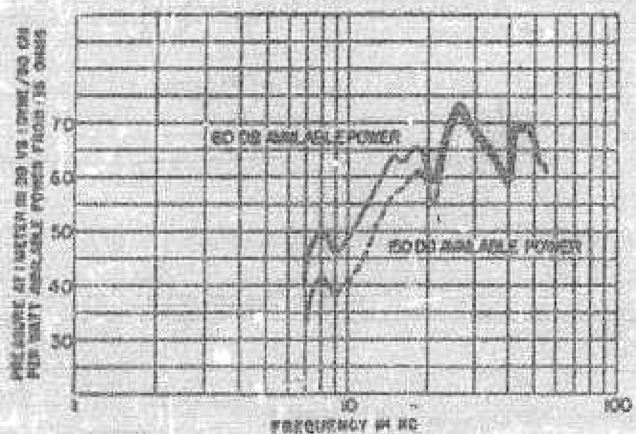

FIGURE 23. Transmitting response. AX-79-1 transducer.

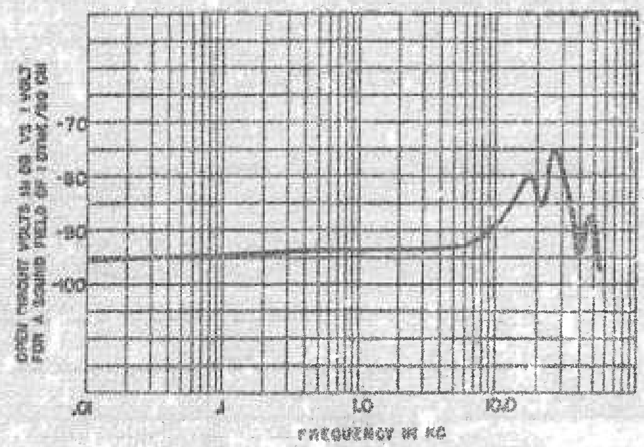

FIGURE 24. Receiving response, AX-79-1 transducer.

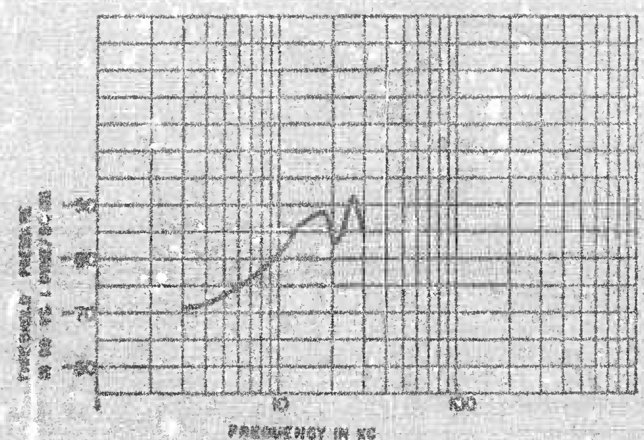

FIGURE 25. Threshold, AX-79-1 transducer.

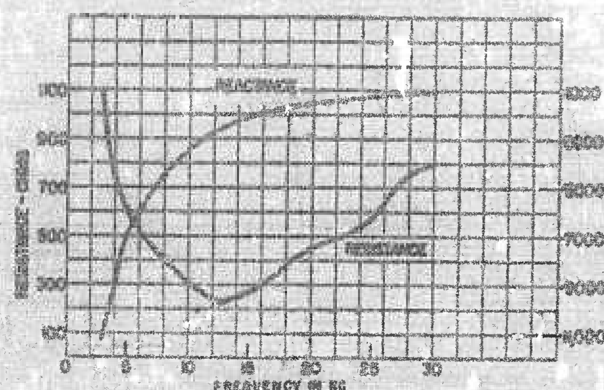

FIGURE 26. Impedance, AX-79-1 transducer.

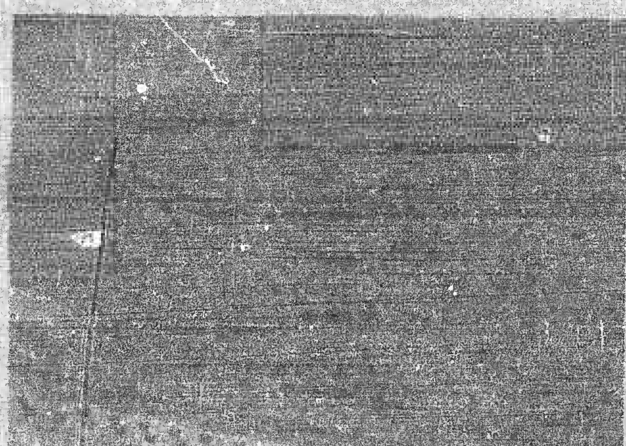

FIGURE 27. AX-79-1 transducer.

[illegible] AX-83 Hydrophone

Type: X-Cut Rochelle Salt Crystal.

Designer and Manufacturer: Brush Development Company.

Use: Measurement standard.

Description: The AX-83 is similar in size, appearance, and mechanical construction to the C28. The crystal unit is near the middle of a 2.5 in. diameter, oil-filled, rubber-covered tube, the overall length of the device being about 14 in. It is nondirectional up to about 30 kc.

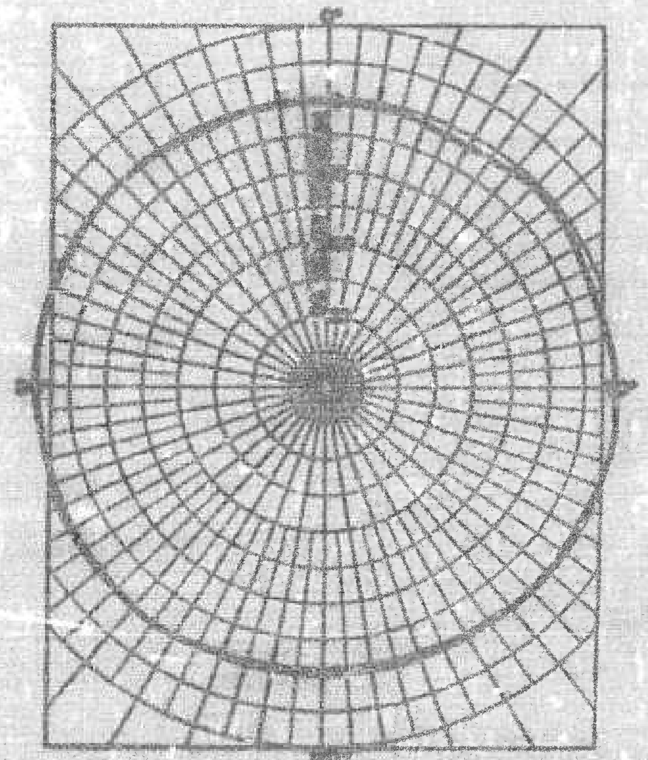

FIGURE [illegible]. Directivity pattern, AX-83 transducer at 18 kc.

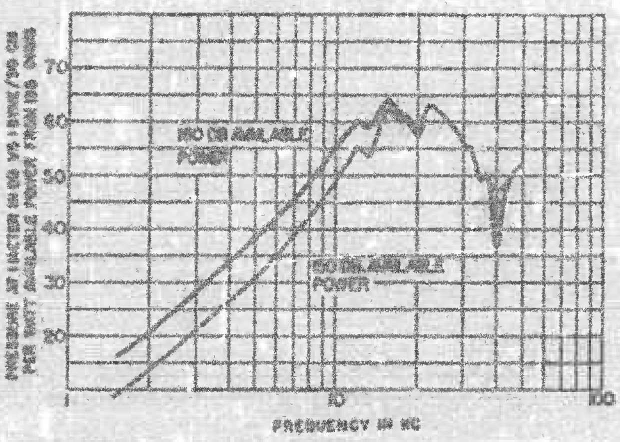

FIGURE 29. Transmitting response, AX-83 transducer.

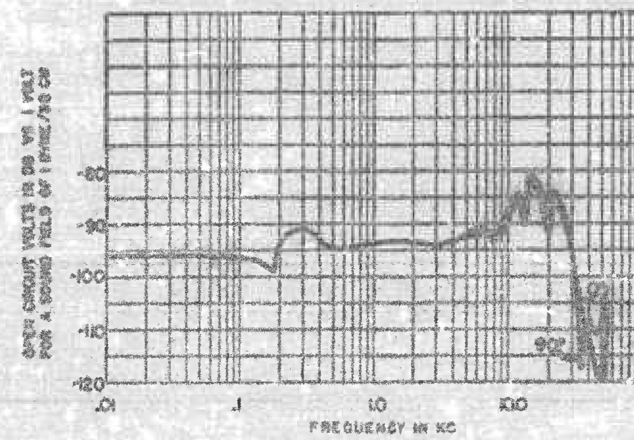

FIGURE 30. Receiving response, AX-83 transducer.

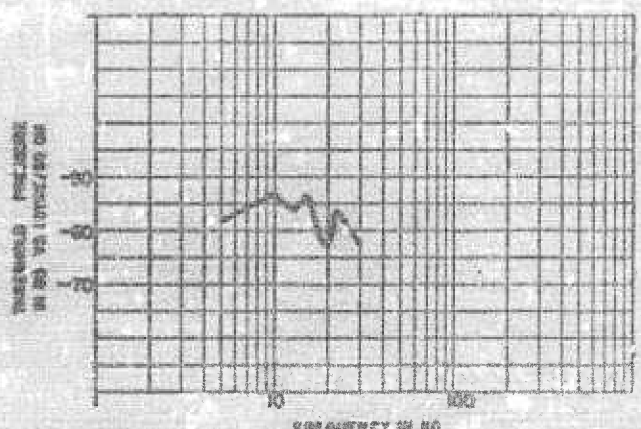

FIGURE 31. Calculated threshold, AX-83 transducer.

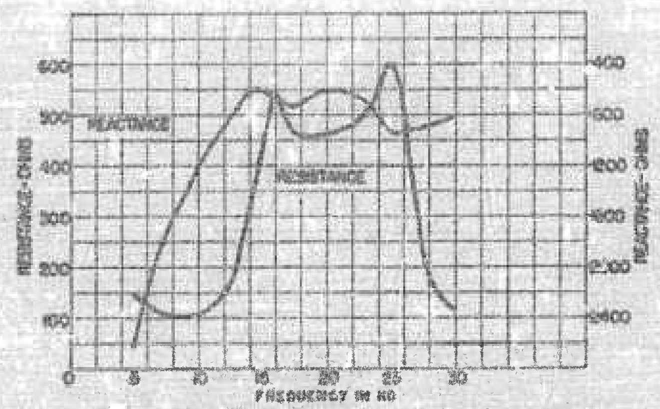

FIGURE 32. Impedance, AX-83 transducer.

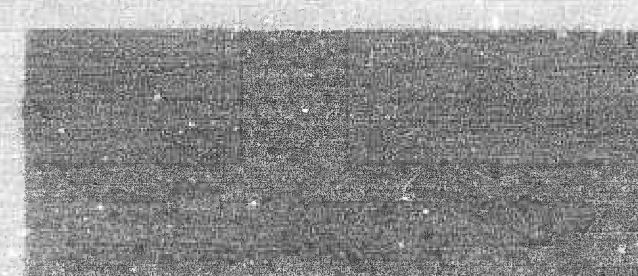

FIGURE 33. AX-83 transducer.

7.4.7 AX-114A Hydrophone

Type: ADP Crystal.

Designer and Manufacturer: Brush Development Company.

Use: Subsonic listening unit for mines.

Description: The ADP crystals in this hydrophone are mounted on a metal plate and have a diaphragm in front of them. The space between the diaphragm and the rubber cover is oil-filled. The housing incorporates a mounting flange.

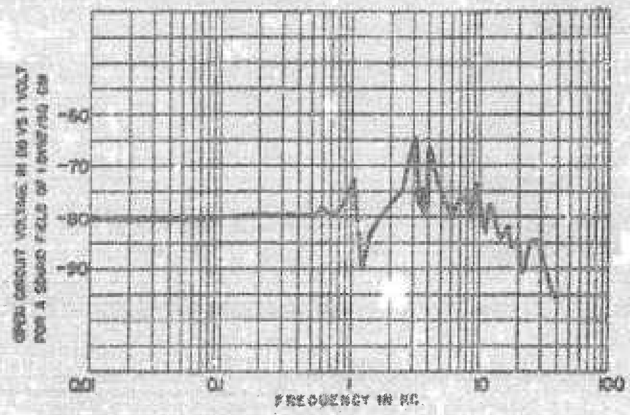

FIGURE 34. Receiving response, AX-114A hydrophone.

FIGURE 35. AX-114A hydrophone.

7.6.8 AX-128 Transducer

Type: ADP Crystal.

Designer and Manufacturer: Brush Development Company.

Use: For practice target.

Description: The AX-128 transducer can be used as either hydrophone or projector in the 20- to 50-kc range. It is approximately nondirectional in a plane normal to the transducer axis, but somewhat directional in a plane containing this axis. It is about 3 in. in diameter, 11 in. in length, rubber-covered and oil-filled.

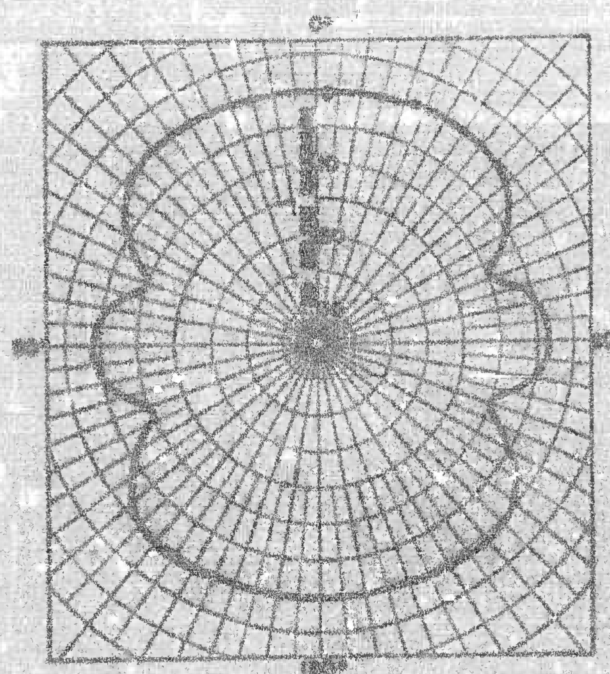

FIGURE 36. Directivity pattern, AX-128 transducer at 25 kc in plane normal to axis.

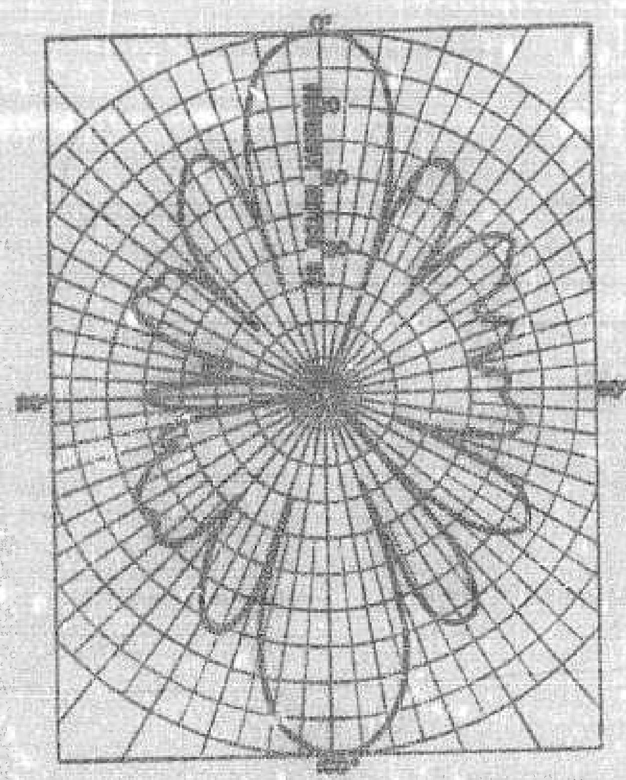

FIGURE 37. Directivity pattern, AX-128 transducer at 25 kc in plane containing axis.

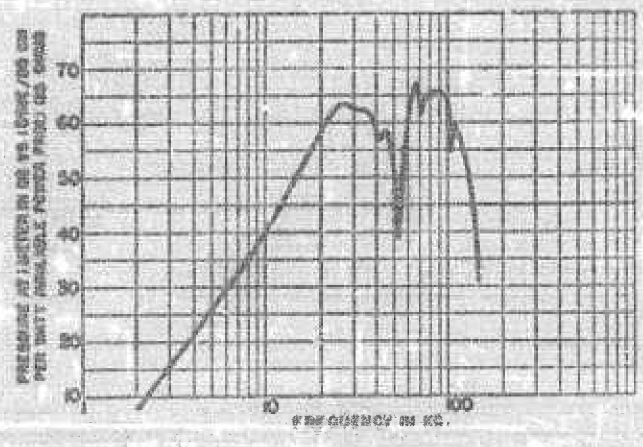

FIGURE 38. Transmitting response, AX-128 transducer.

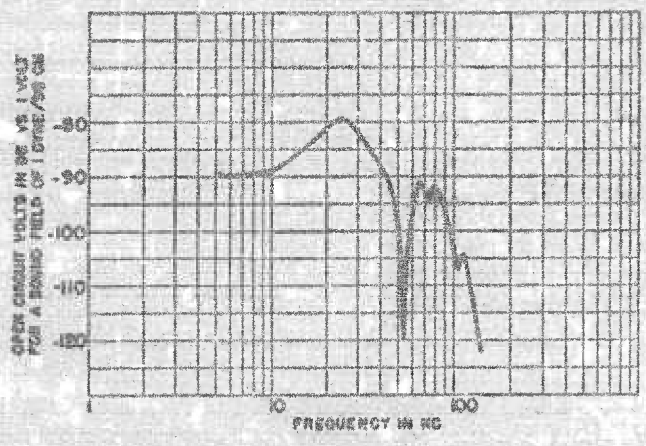

FIGURE 39. Receiving response, AX-128 transducer.

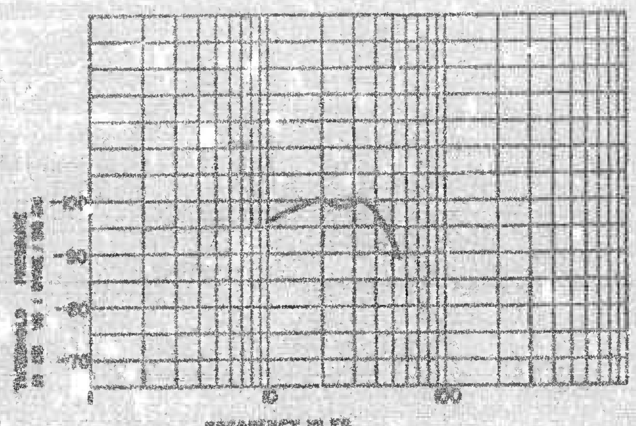

FIGURE 40. Threshold, AX-128 transducer.

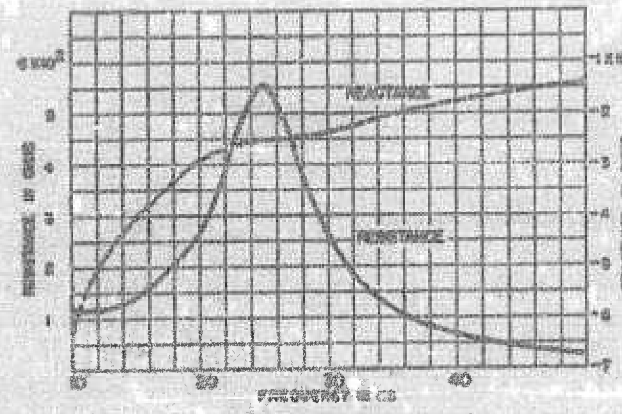

FIGURE 41. Impedance, AX-128 transducer.

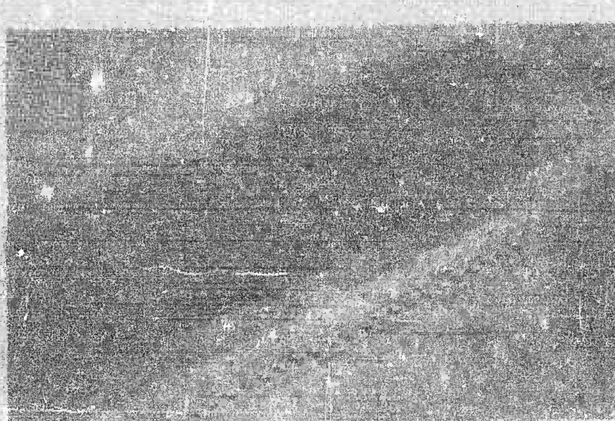

FIGURE 42. AX-128 transducer.

7.6.9 AX-131 Transducer

Type: X-Cut Rochelle Salt Crystal.

Designer and Manufacturer: Brush Development Company.

Use: Scanning transducer for testing materials.

Description: The AX-131 is a high-frequency transducer designed for use in the region of 400 kc. It is oil-filled with a rubber cover over the active face. The overall length of the device is about 5 in. and the diameter of the face about 2 in. The radiating area is rectangular and about 1.5 in. long by 1 in. wide.

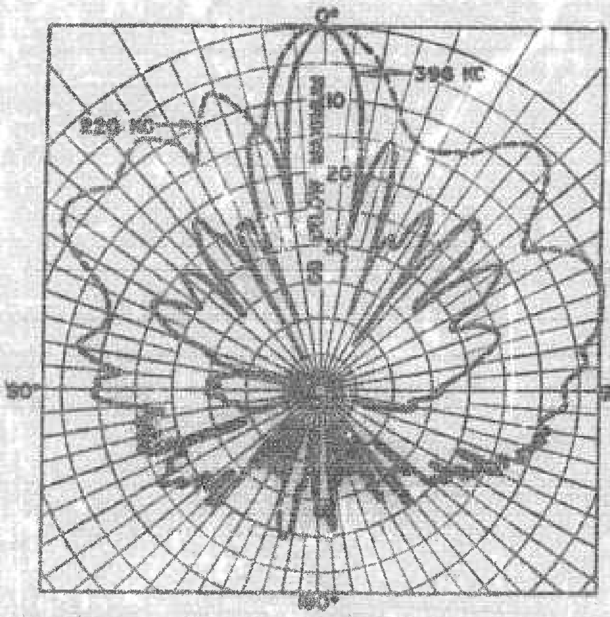

FIGURE 43. Directivity patterns, AX-131 transducer in plane containing axis and long dimension of crystal unit.

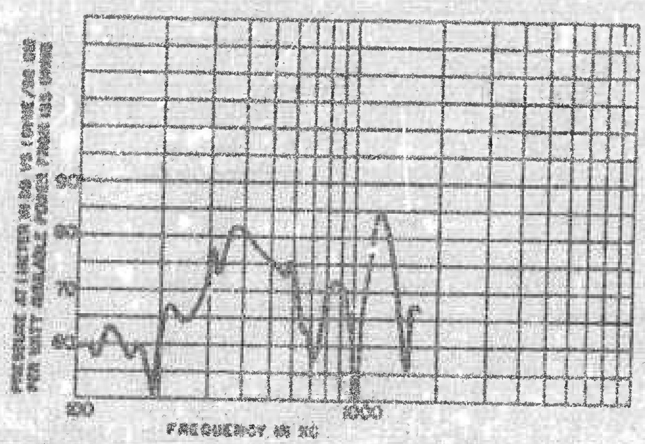

FIGURE 44. Transmitting response, AX-131 transducer.

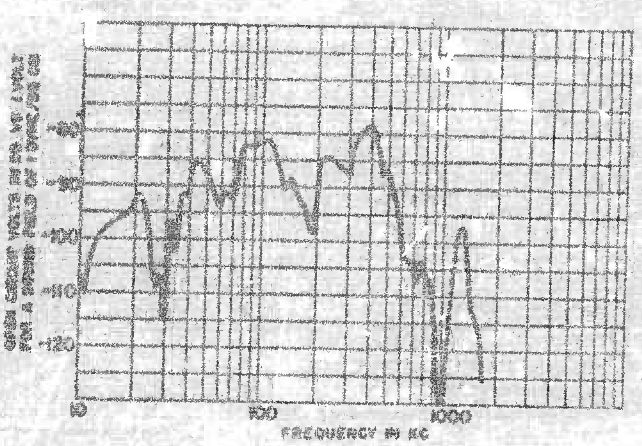

FIGURE 45. Receiving response, AX-131 transducer.

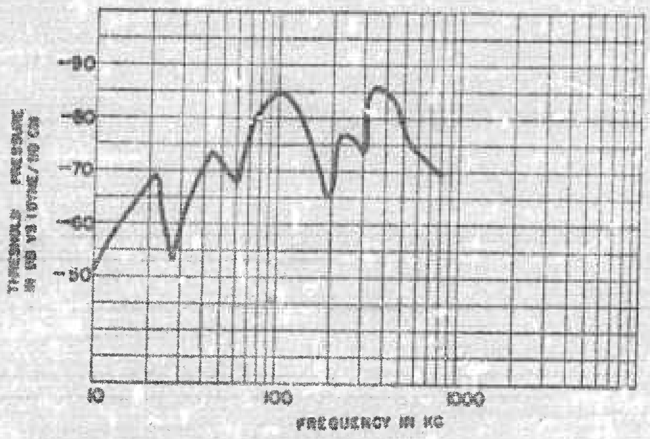

FIGURE 46. Calculated threshold, AX-131 transducer.

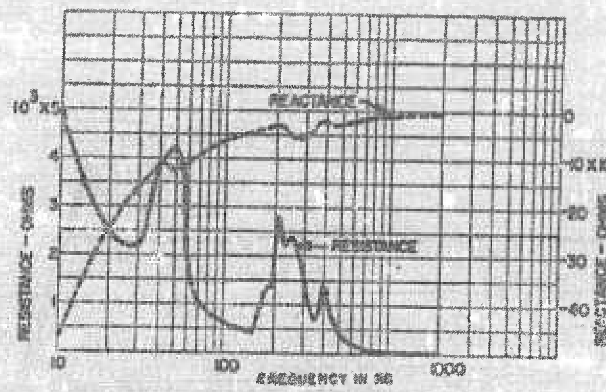

FIGURE 47. Impedance, AX-131 transducer.

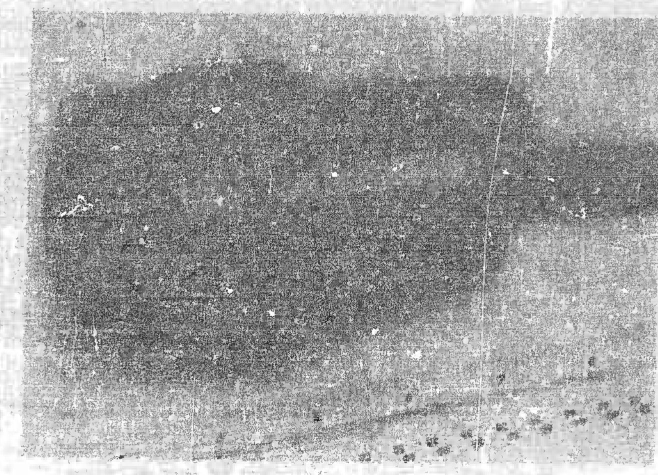

FIGURE 48. AX-131 transducer.

7.4.10 C10 Hydrophone

Type: X-Cut Quartz Crystal.

Designer and Manufacturer: Brush Development Company.

Reference: NDRC Report No. C4-sr20-148, July 27, 1942.[5]

Use: Measurement standard.

Description: This instrument has the same dimensions as the C11-A1 standard hydrophone described in Chapter 1, except that the diameter of the pickup head is $\frac{25}{32}$ in. It contains a built-in preamplifier and calibration circuit. The preamplifier is operated from dry cells and the unit is supplied with 28 ft of 5-conductor cable.

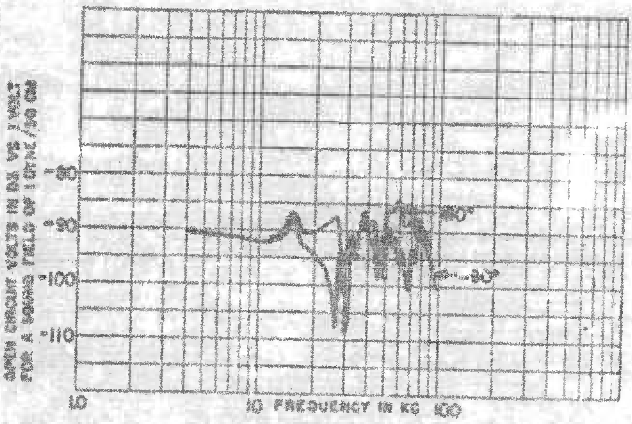

FIGURE 49. Receiving response, C10 hydrophone.

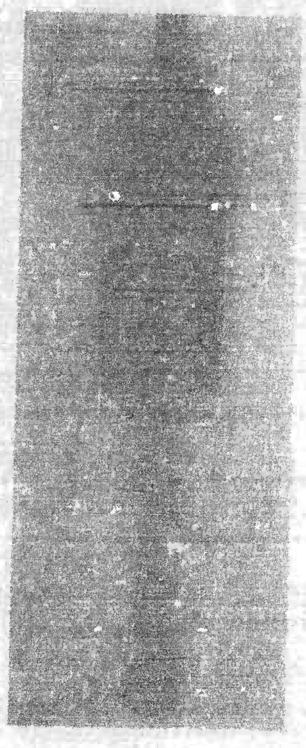

FIGURE 50. C10 hydrophone.

7.6.11 C23 Hydrophone

Type: X-Cut Rochelle Salt Crystal.

Designer and Manufacturer: Brush Development Company.

Reference: NDRC Report No. C4-sr20-298, November 20, 1942.[150]

Use: High-pressure measurements.

Description: A heavy cylindrical rubber body 15 in. long and 2.5 in. in diameter contains the crystals which are immersed in oil. A 1.75-in. wide metal band around the body adds mechanical strength. The unit also contains, as an integral part, a step-down transformer from which the output is taken. The output impedance of the unit is, therefore, low enough to permit use of long cables without appreciable coupling loss. The data given were measured at the end of a 25-ft cable. A response measurement which was made across the secondary of a special grid transformer at the end of the cable is also shown.

This instrument replaced Brush model XE1.

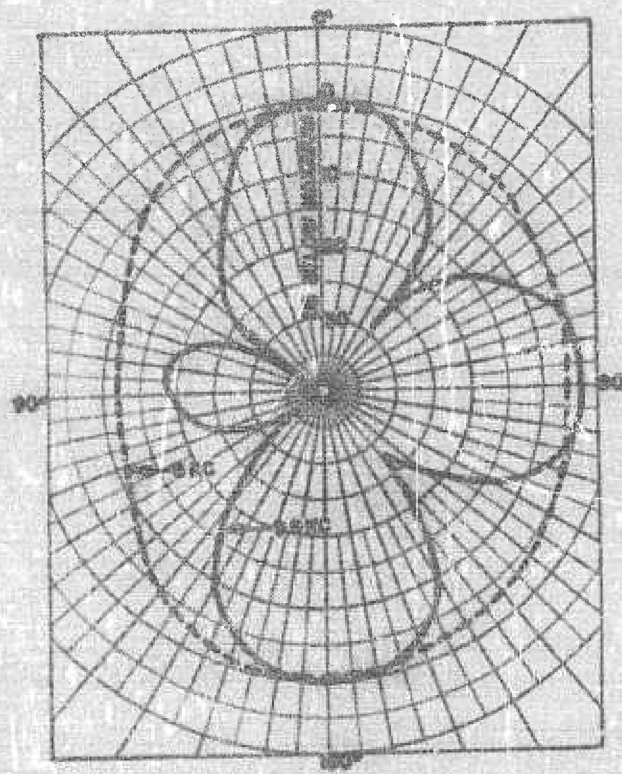

FIGURE 51. Directivity patterns, C23 hydrophone in a plane normal to axis.

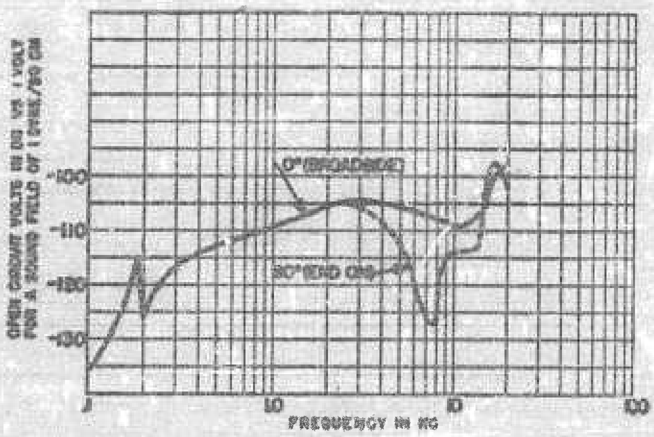

FIGURE 52. Receiving response, C23 hydrophone measured at cable terminals.

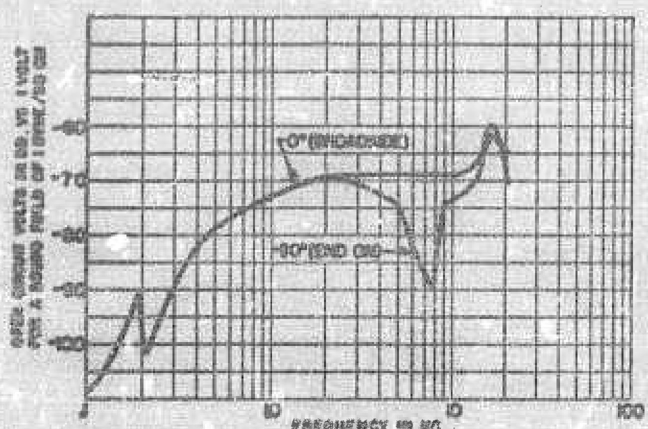

FIGURE 53. Receiving response, C23 hydrophone measured across secondary of transformer at end of cable.

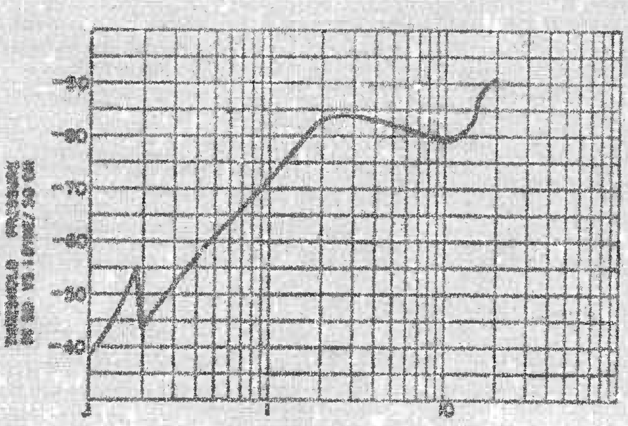

FIGURE 54. Calculated threshold, C23 hydrophone.

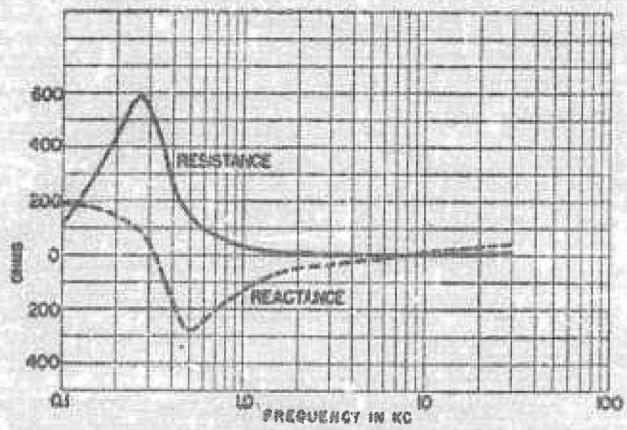

FIGURE 55. Impedance, C23 hydrophone.

FIGURE 56. C23 hydrophone.

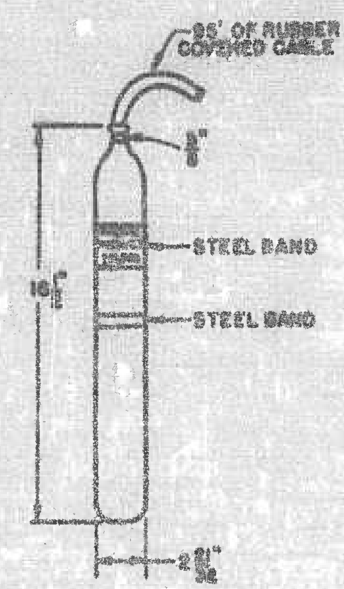

FIGURE 57. Dimensional drawing, C23 hydrophone.

7.6.18 C37 Hydrophone

Type: X-Cut Rochelle Salt Crystal.

Designer and Manufacturer: Brush Development Company.

Reference: NDRC Report No. C4-sr20-286, October 5, 1942.[182]

Use: Listening, harbor defense.

Description: The C37 is a line hydrophone 4.5 ft long. It consists of eight C23 crystal units arranged in a line in a rubber-covered, oil-filled tube. The units are connected in parallel. A built-in transformer permits the use of several hundred feet of cable with the device. It is essentially nondirectional in a plane normal to its axis. The preproduction model was the AX-10. The C37-5 and C37-6 differ slightly from C37 in mechanical details. The main difference is in the rubber cover which is ρc rubber in the C37 and ordinary rubber in the other two. The C37-5 is a towing hydrophone and the C37-6 is used for harbor defense.

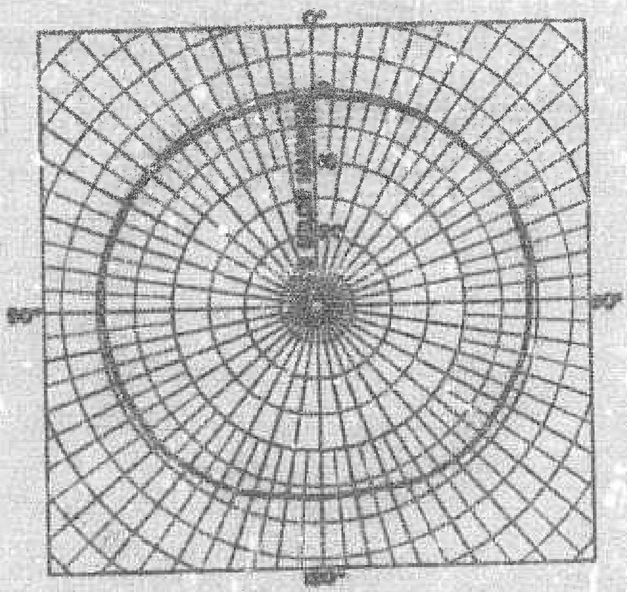

FIGURE 58. Directivity pattern, C37 hydrophone at 12 kc.

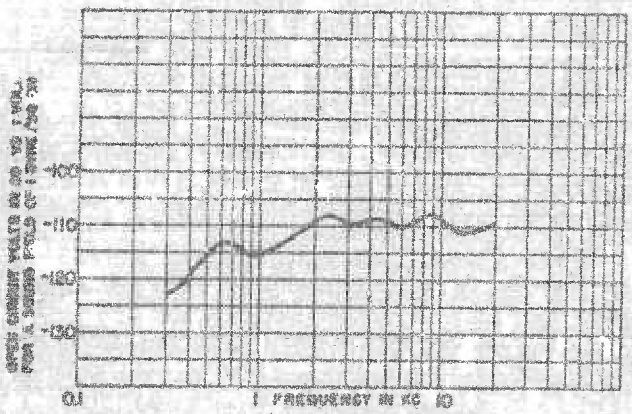

FIGURE 59. Receiving response, C37 hydrophone measured at cable terminals.

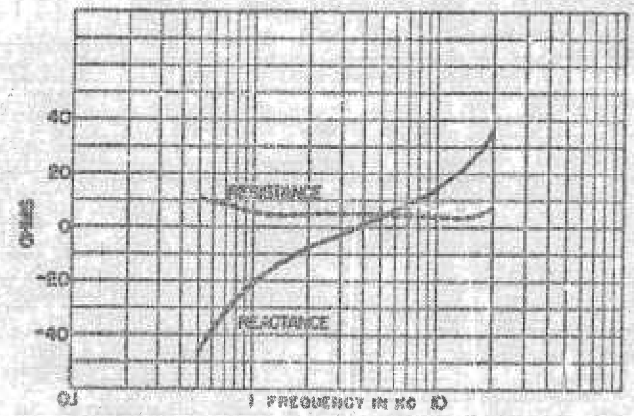

FIGURE 62. Impedance, C37 hydrophone.

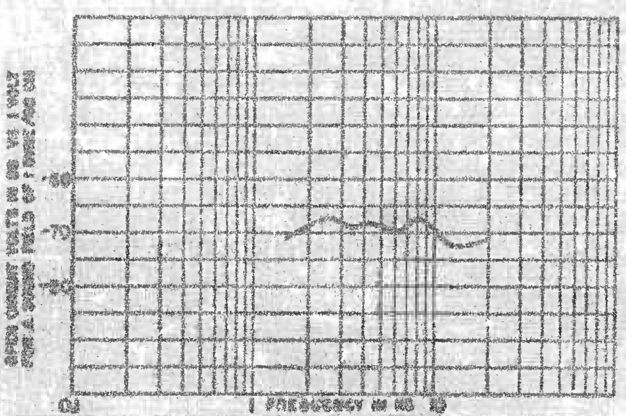

FIGURE 60. Receiving response, C37 hydrophone measured at output of coupling transformer.

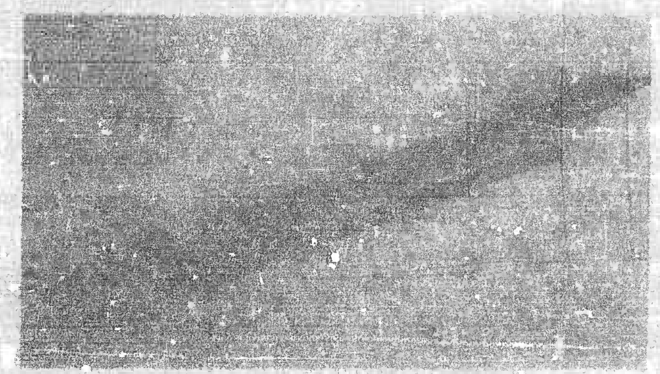

FIGURE 63. C37 hydrophone.

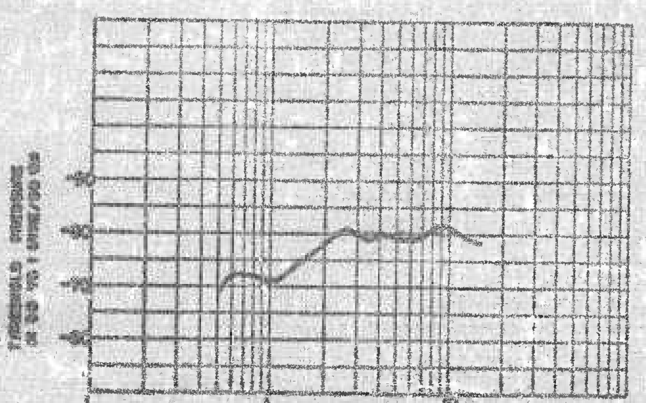

FIGURE 61. Calculated threshold, C37 hydrophone.

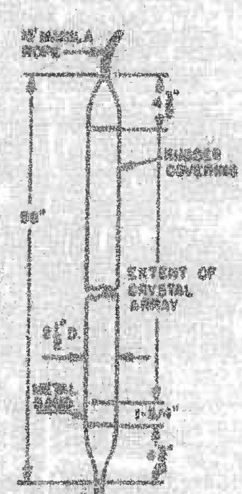

FIGURE 64. Dimensional drawing, C37 hydrophone.

7.6.13 C43 Hydrophone

Type: X-Cut Rochelle Salt Crystal.

Designer and Manufacturer: Brush Development Company.

Reference: NDRC Report No. 6.1-sr20-871, May 14, 1943.[196]

Use: With expendable radio sono buoy.

Description: The crystals are mounted in an oil-filled steel, cylindrical, tubular container covered with sound-transparent rubber. The overall length is 8.5 in. The leads in a single rubber-covered cable are brought out through a hemispherical metal cap at the end of the unit farthest from the crystal assembly.

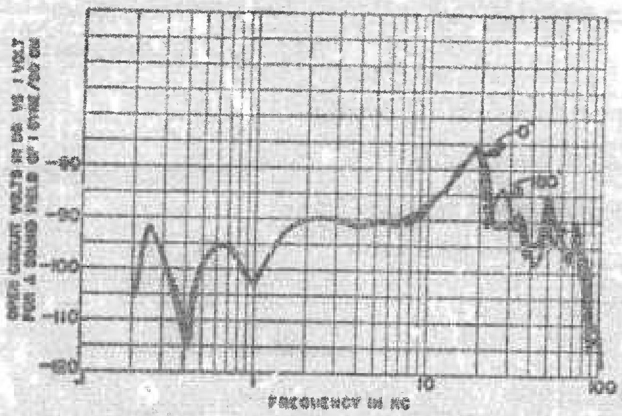

FIGURE 65. Receiving response, C43 hydrophone.

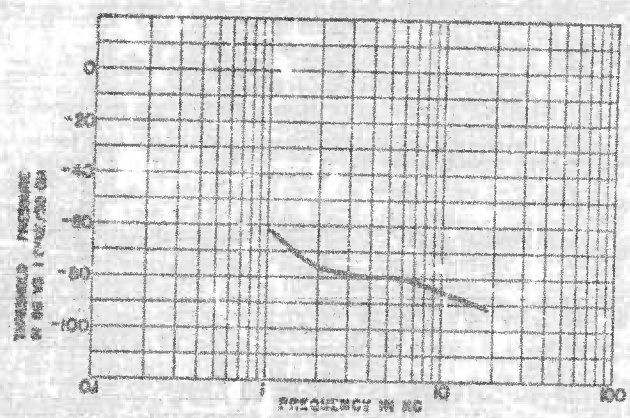

FIGURE 66. Calculated threshold, C43 hydrophone.

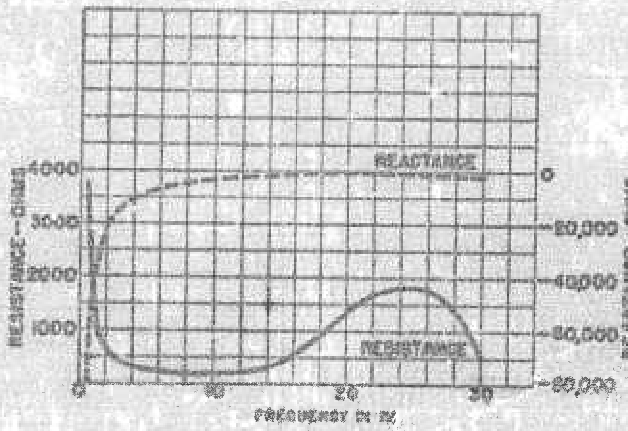

FIGURE 67. Impedance, C43 hydrophone.

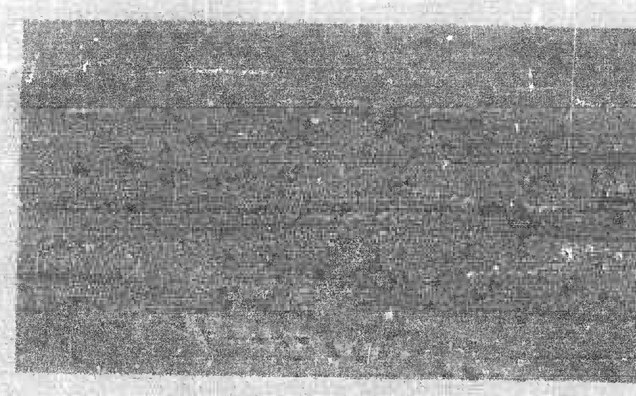

FIGURE 68. C43 hydrophone.

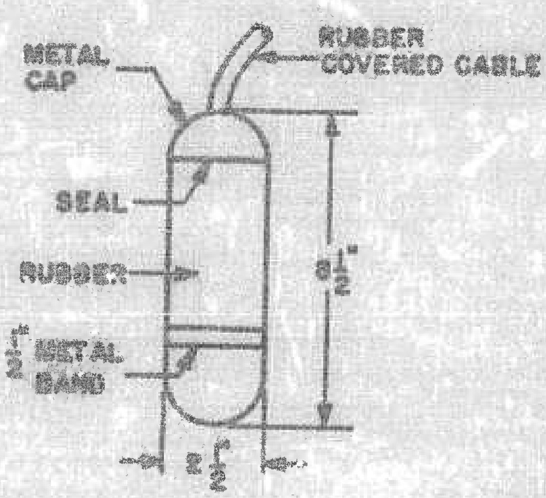

FIGURE 69. Dimensional drawing, C43 hydrophone.

7.6.14 C44, AX-6, AX-6-F Hydrophones

Type: X-Cut Rochelle Salt Crystal.
Designer and Manufacturer: Brush Development Company.
References: NDRC Report No. C4-sr20-285, September 30, 1942.[181]
NDRC Report No. C4-sr20-299, November 26, 1942.[187]

Description: The C44, AX-6, and AX-6-F instruments are the same in appearance. They are contained in a cylindrical housing $2\frac{1}{2}$ in. in diameter by approximately 16 in. in length, covered with sound-transparent rubber. This housing is similar to that used for the C28 type hydrophone. (See photograph and drawing of C28, Figures 56 and 57.) Each dual-pattern hydrophone consists of three units of X-cut Rochelle salt crystals, which are arranged along the hydrophone axis. Two of the units, each approximately 2 in. long, are connected in parallel and comprise the directional array of the hydrophone. The other unit functions by itself and gives a pattern which is essentially nondirectional. In the C44 hydrophone the spacing between the centers of the units used in the directional array is about 5 in., in the AX-6 about 4 in., and slightly less in the AX-6-F. The nondirectional unit is smaller than the array units. In the AX-6 hydrophone the nondirectional unit is located at the end of the hydrophone farthest from the leads. In the C44 hydrophone it is located between the two elements of the directional unit.

Each hydrophone contains two step-down transformers, one for the nondirectional unit and the other for the array units.

The dual-pattern hydrophone system depends for its operation on the relative response of the array and of the separate unit. Operation of the associated electric system occurs when the output of the array exceeds that of the separate unit. Amplifiers with suitable gains are used in the output circuits to provide this relation over the desired angular range. The reliability of operation of the system for different angular positions of the hydrophone with respect to the direction of sound incidence then depends on the difference in directivity of the array and that of the separate unit.

The data shown are for a C44, but the other instruments do not differ appreciably.

Impedance in ohms:

Frequency (kc)	Directional unit	Nondirectional unit
1	$6.5 - j61.4$	$82.1 - j154.0$
5	$5.2 + j\,0.15$	$5.2 - j\,21.4$
7	$5.0 + j\,5.7$	$5.0 - j\,10.1$
8	$5.1 + j\,8.4$	$5.0 - j\,6.2$
9	$5.2 + j10.7$	$5.2 - j\,2.5$
15	$5.5 + j23.1$	$4.8 + j\,13.4$

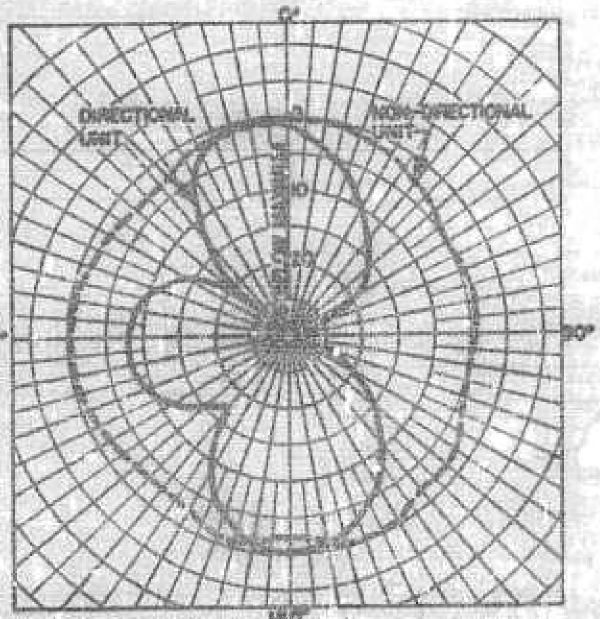

FIGURE 70. Directivity patterns, C44 hydrophone at 8 kc.

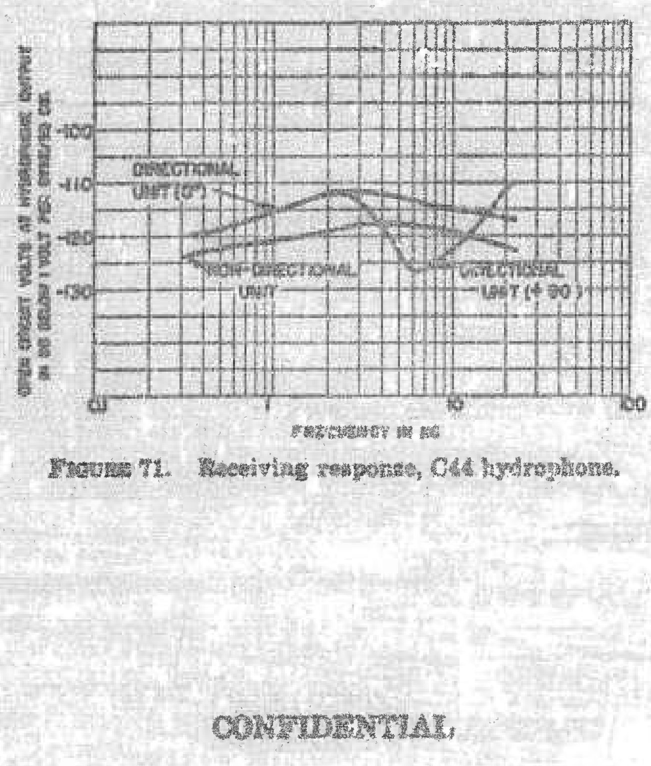

FIGURE 71. Receiving response, C44 hydrophone.

7.6.16 C49 Hydrophone

Type: X-Cut Rochelle Salt Crystal.
Designer and Manufacturer: Brush Development Company.
Reference: NDRC Report No 6.1-sr20-1185, November 12, 1943.[210]
Use: Acoustic mines.
Description: The four crystal assemblies are cemented to the back of the metal case and the sides of each assembly are covered with Corprene. The housing is oil-filled, covered with a metal diaphragm and enclosed by a rubber cover. The hydrophone is nondirectional up to at least 15 kc.

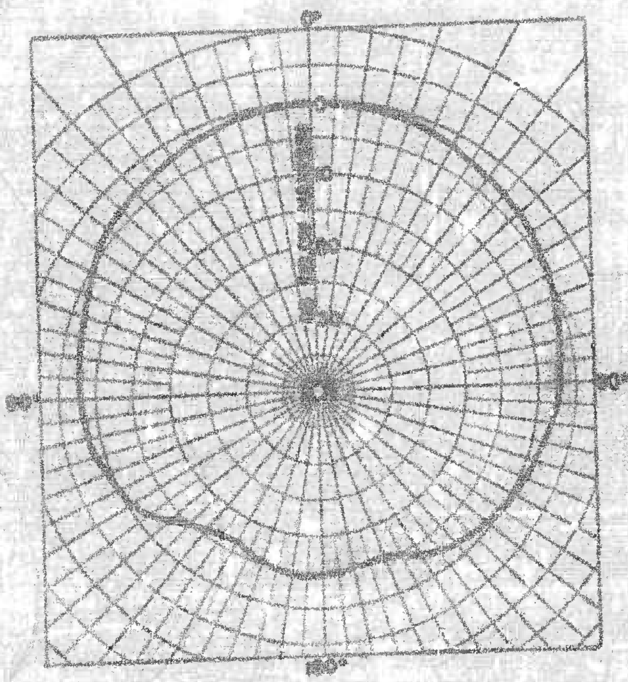

FIGURE 72. Directivity pattern, C49 transducer at 2.65 kc.

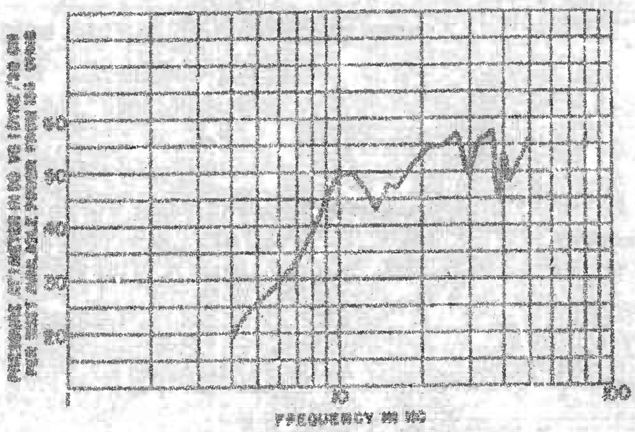

FIGURE 73. Transmitting response, C49 transducer.

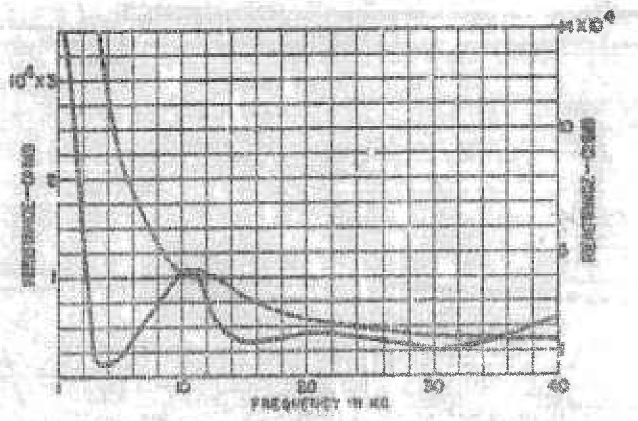

FIGURE 76. Impedance, C49 transducer.

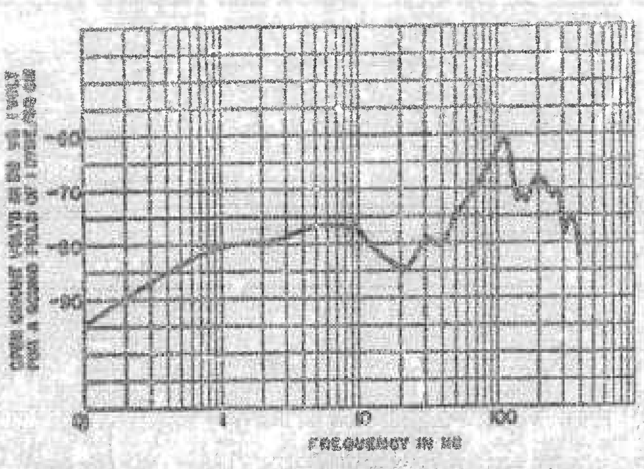

FIGURE 74. Receiving response, C49 transducer.

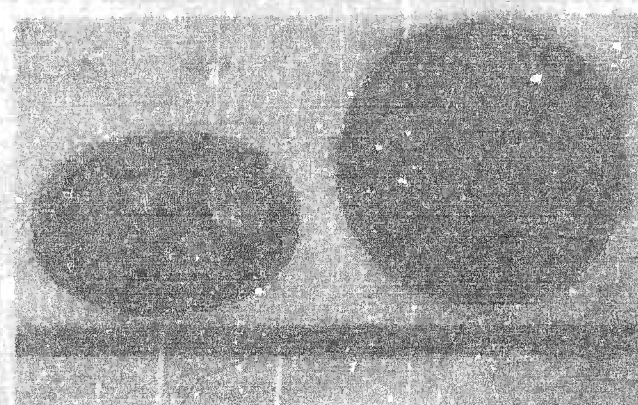

FIGURE 77. C49 transducer with crystals exposed.

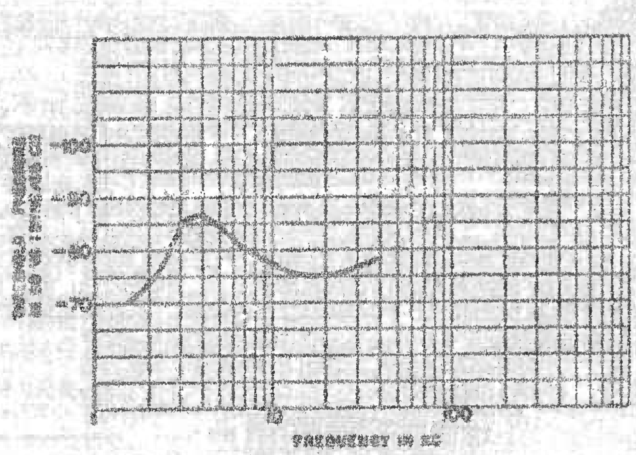

FIGURE 75. Calculated threshold, C49 transducer.

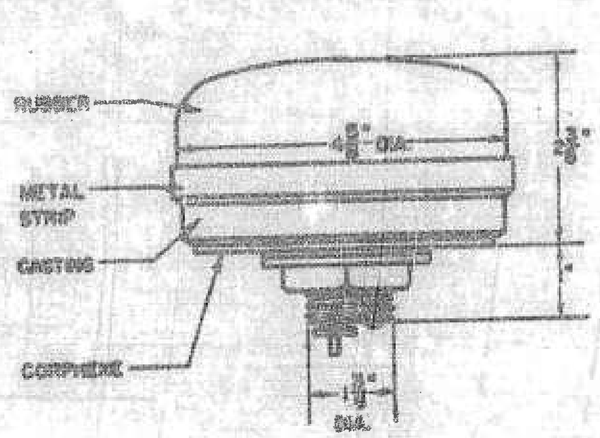

FIGURE 78. Dimensional drawing, C49 transducer.

7.8.16 C50 Hydrophone

Type: X-Cut Rochelle Salt Crystal.

Designer and Manufacturer: Brush Development Company.

Reference: NDRC Report No. 6.1-sr20-890, June 19, 1943.[107]

Use: Measurement standard.

Description: The crystal assembly and preamplifier are contained in a cylindrical metal tube covered with sound-transparent rubber. Around the crystal is a sound window approximately 1.5 in. long. A 10-ohm calibrating resistor is included to permit measurement of the open-circuit crystal voltage. Calibrating leads, preamplifier output leads, and preamplifier supply voltage leads are brought out in a single cable. The device is nondirectional in a plane normal to the axis.

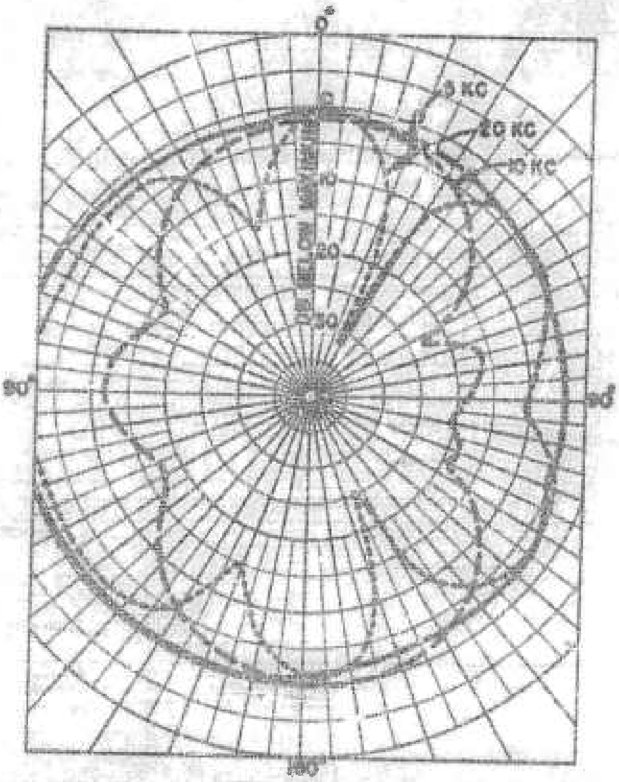

Figure 79. Directivity pattern, C50 hydrophone.

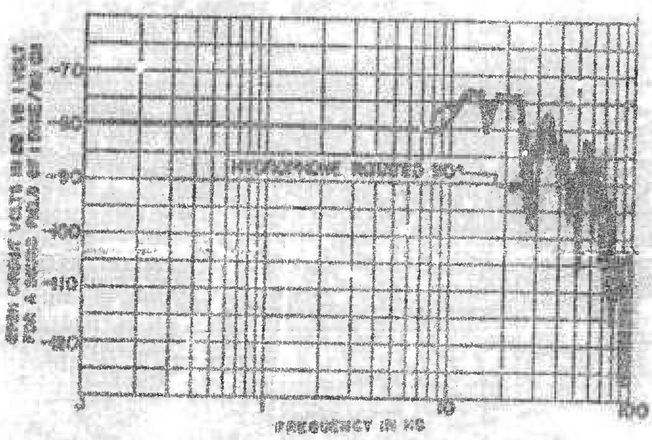

Figure 80. Receiving response, C50 hydrophone.

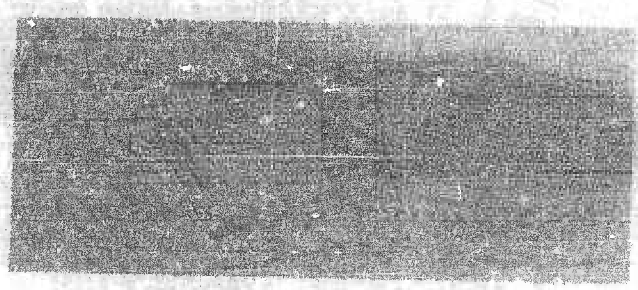

Figure 81. C50 hydrophone.

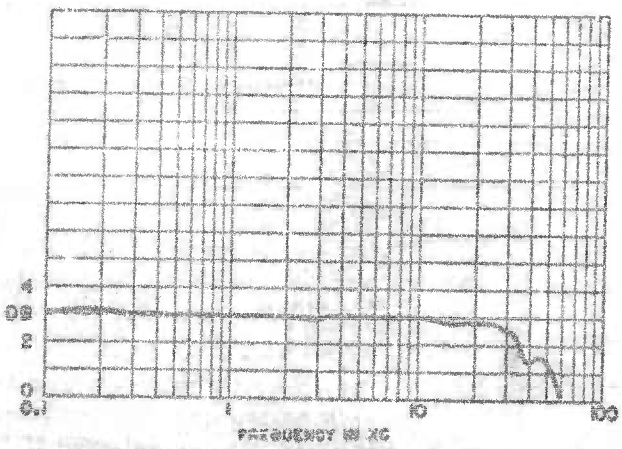

Figure 82. Voltage gain of preamplifier, C50 hydrophone.

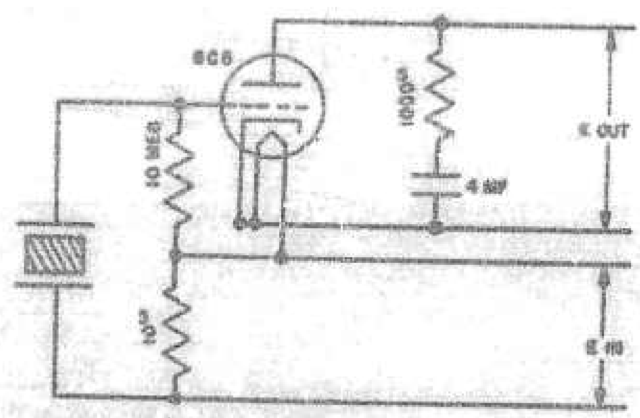

Figure 83. Preamplifier circuit, C50 hydrophone.

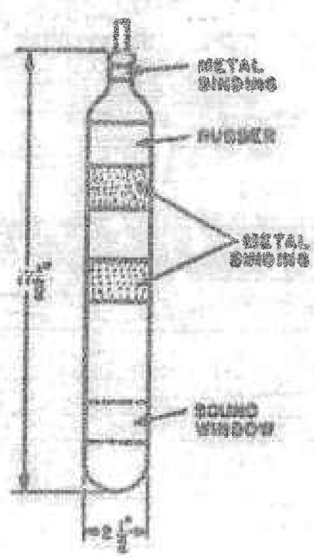

Figure 84. Dimensional drawing, C50 hydrophone.

7.6.17

4A Cable Hydrophone

Type: Electromagnetic.
Designer: Bell Telephone Laboratories.
Reference: NDRC Report No. 6.1-sr692-661, December 15, 1942.[199]
Use: Harbor protection.

Description: The essential structure of the sound element is shown in the cross section. *A* and *B* are permanent magnets which supply the magnetomotive force for the magnetic circuit. *C* and *D* are soft iron pole pieces, bent into horseshoe shape, which support the coil. The unit is mounted in a brass tube and fitted into the envelope of a standard all-metal radio tube which is then sealed and imbedded in a rubber cover.

The basic structure has been used in the design of several other models containing one or more units combined in a suitable housing to obtain either a pressure or pressure gradient response with a circular, figure-eight, cardioid, or toroidal directivity pattern.

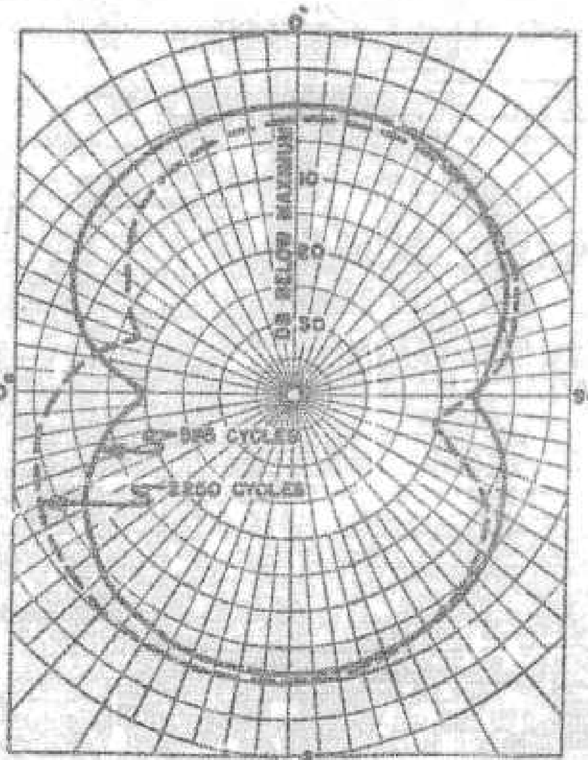

FIGURE 85. Directivity patterns, 4A cable hydrophone.

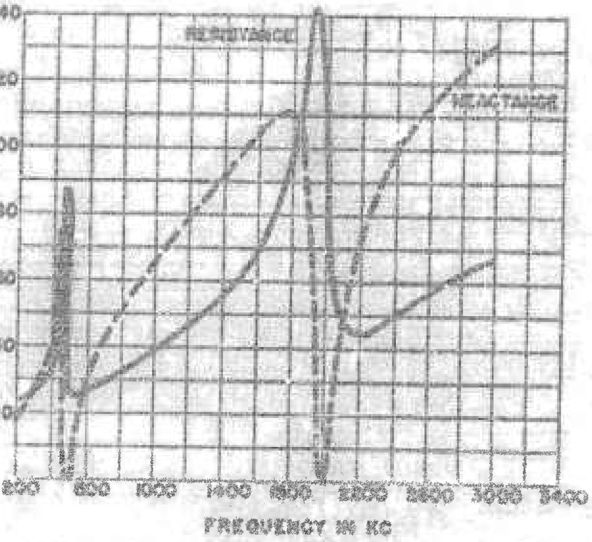

FIGURE 87. Impedance, 4A cable hydrophone.

FIGURE 88. 4A cable hydrophone.

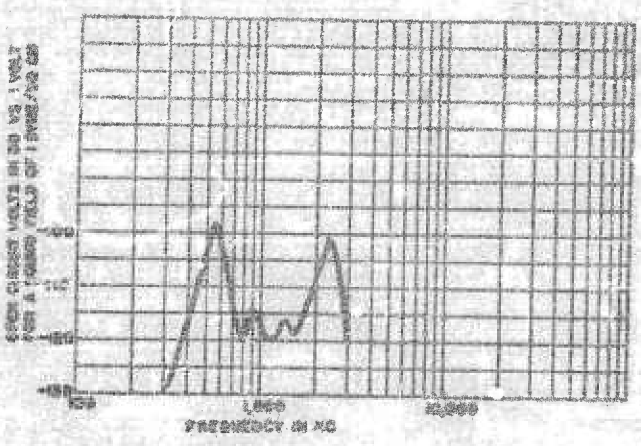

FIGURE 86. Receiving response, 4A cable hydrophone.

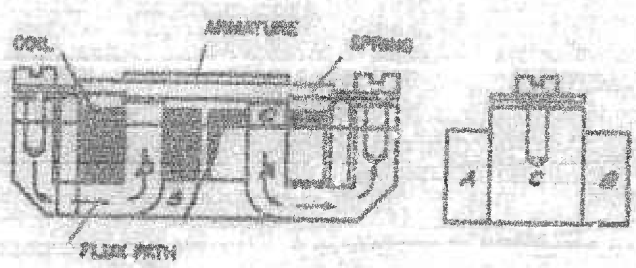

FIGURE 89. Cross section, 4A cable hydrophone.

1.4.18 5A and 5B Hydrophones

Type: X-Cut Rochelle Salt Crystal.
Operating range: Audio frequency.
References: NDRC Report No. C4-sr20-297, November 16, 1942.[188]
NDRC Report No. 6.1-sr692-1698, December 1, 1944.[221]

Description: The 5A and 5B hydrophones were experimental designs used in the study listening systems for patrol craft carried on by BTL on NDRC contrac In these tests, the units were employed individually and in arrays consisting of six hydrophones spaced 6 in. apart, or approximately ½ wavelength at 5 kc. The coupling amplifier used with the 5A hydrophone to provide a low impedance output is replaced in the 5B hydrophone by a transformer.

The 5A and 5B hydrophones are predecessors of the 5C and 5E hydrophones, which have been used as standards by the USRL (see Section 1.4.19).

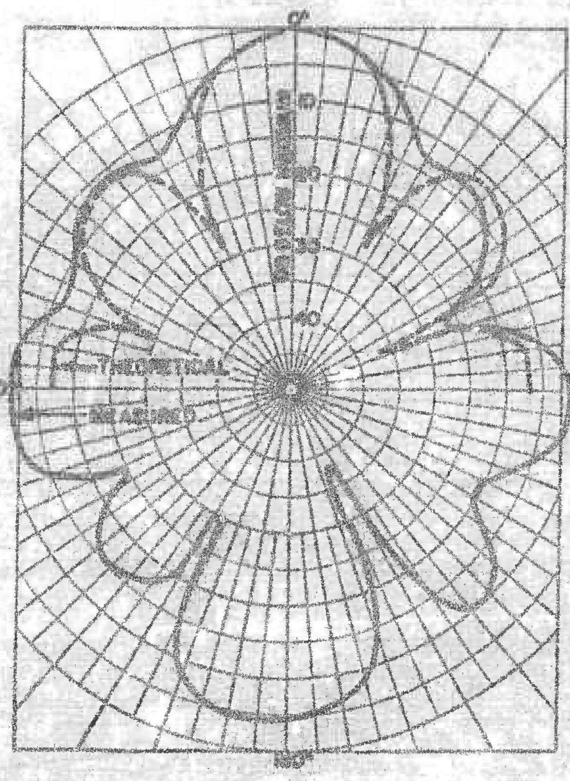

Figure 90. Directivity pattern, 5A hydrophone at 5 kc.

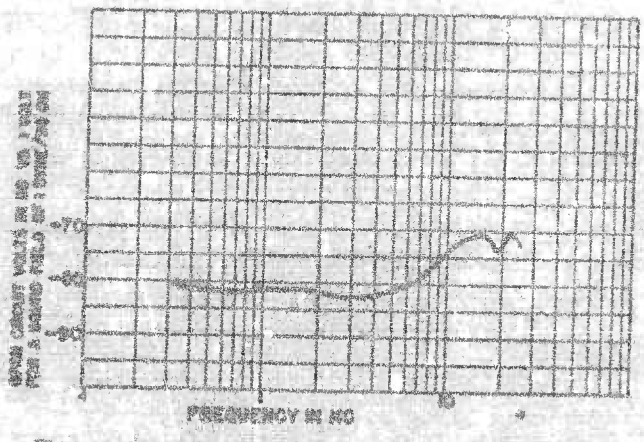

Figure 91. Receiving response, 5A hydrophone.

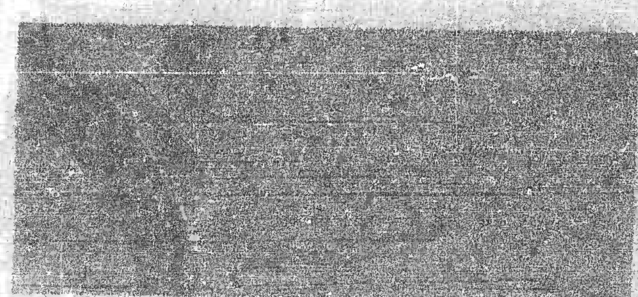

Figure 92. 5A hydrophone.

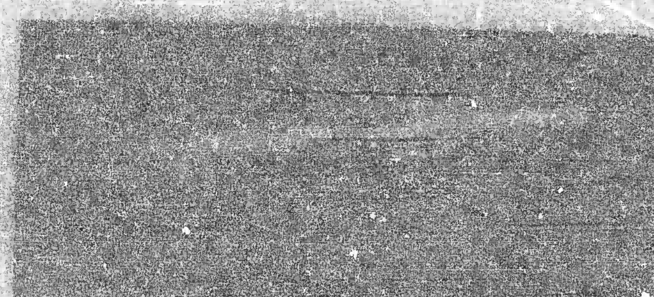

Figure 93. 5B hydrophone.

7.6.39

7A Hydrophone

Type: X-Cut Rochelle Salt Crystal.

Designer: Bell Telephone Laboratories.

Reference: NDRC Report No. 6.1-sr692-1698, December 1, 1944.[321]

Use: For supersonic listening from patrol craft.

Description: The 7A hydrophone is an experimental design used in the study of an electrically steered supersonic listening system for patrol craft carried on by BTL on NDRC contract. The supersonic array consisted of two assemblies of Rochelle salt crystal hydrophones. Each hydrophone employed a crystal block 0.7 in. square, mounted on a heavy steel resonator and covered with a diaphragm 1x2⅛ in. Except for the size, the construction is very similar to that of the 5-type hydrophone. Nine of these crystal elements, each with its own diaphragm, were assembled in a bronze casting.

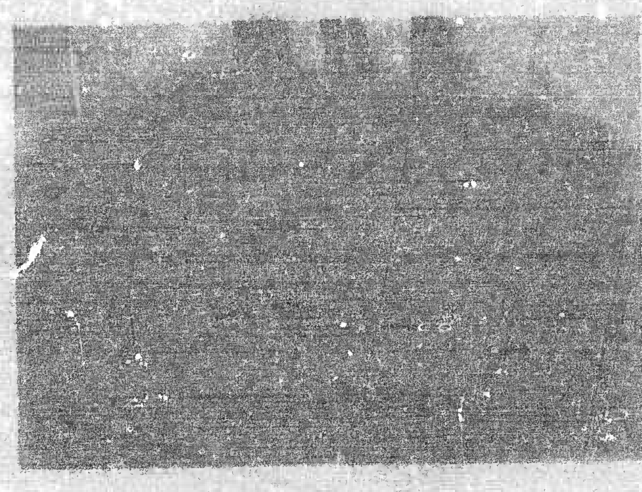

FIGURE 94. 7A hydrophone.

7.6.20

8A Hydrophone

Type: Electromagnetic, Pressure Gradient.
Designer: Bell Telephone Laboratories.
Use: With practice attack meter.
Description: The assembly consists of four electromagnetic, inertia type units, similar to the element in the 4A hydrophone (see Section 7.6.17), mounted inside a spherical aluminum shell. The sphere and lead wires are vulcanized in rubber. A square steel bar is clamped within the sphere along a diameter, and to each of its four faces is fastened a soft iron armature. The 4A units are then suspended by a flat spring to the armatures.

The theory of operation is as follows: The comparatively heavy magnet assembly remains motionless, while the sphere and armatures move with the pressure gradient in the sound field. Opposing units are connected in series, each pair giving a figure-eight, or cosine, pattern. The sign of the voltage generated depends on the direction in which the armature moves from its rest position. Thus for sound incident at the angle θ in the explanatory diagram the voltage developed will be proportional to $+A$ and $+B$. For the reverse directions the voltages are $-A$ and $-B$. Hence the direction of the incoming signal of the explosive wave is indicated without ambiguity.

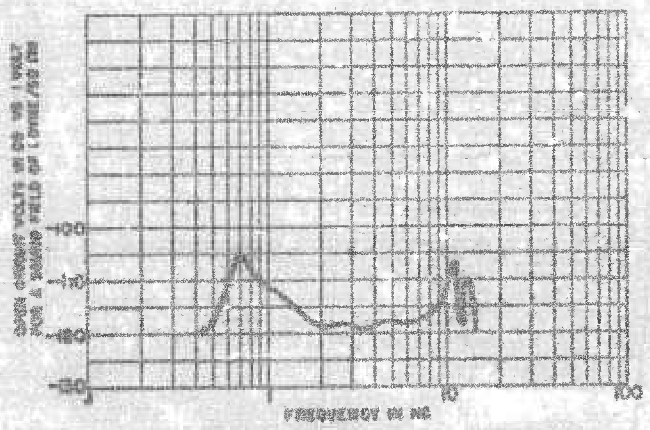

Figure 95. Receiving response, 8A hydrophone.

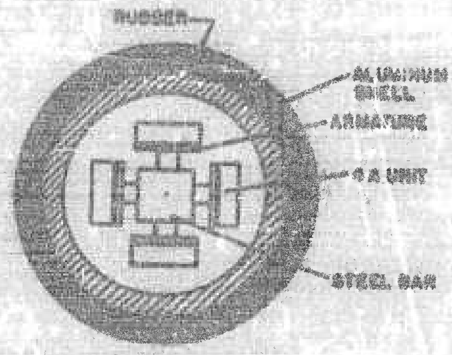

Figure 97. Cross section, 8A hydrophone.

Figure 96. 8A hydrophone.

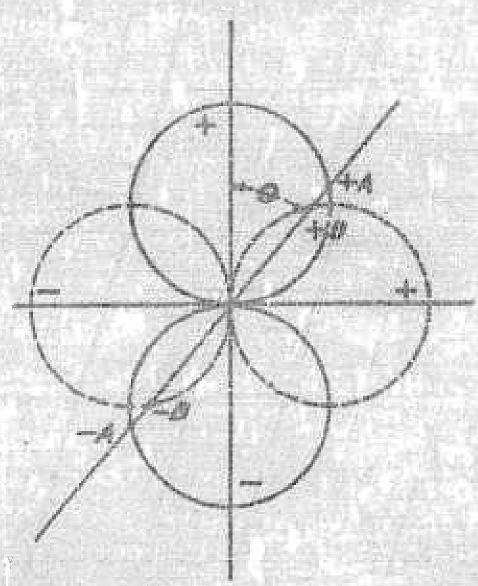

Figure 98. Explanatory diagram of operation, 8A hydrophone.

7.6.21 9A Hydrophone

Type: Electromagnetic, Pressure Gradient.
Designer: Bell Telephone Laboratories.
Reference: NDRC Report No. 6.1-sr692-1698, December 1, 1944.[221]
Use: Listening from small patrol boats.

Description: The 9A hydrophone is similar to the 8A pressure gradient hydrophone (see Section 7.6.20) employing two 4A units (see Section 7.6.17) enclosed in a spherical shell. The distinguishing feature is that an air space is enclosed in the rubber covering, which results in a cardioid form of directivity pattern. A brass-lined, watertight air cell and the butyl rubber covering cause a phase shift between sound at the front and back of the hydrophone, producing a cardioid directivity pattern.

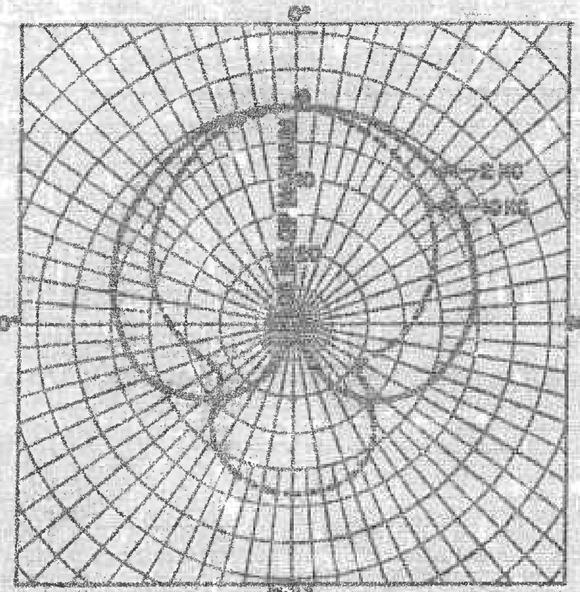

Figure 99. Directivity pattern, 9A hydrophone.

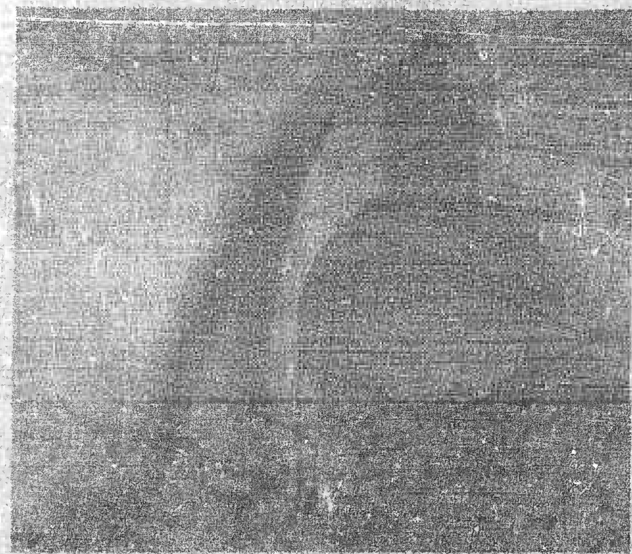

Figure 101. 9A hydrophone.

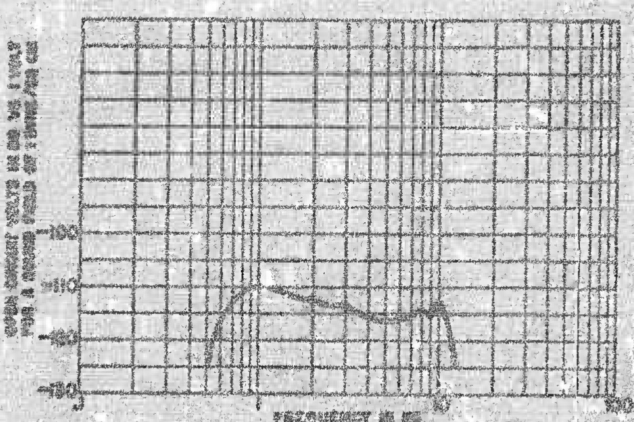

Figure 100. Receiving response, 9A hydrophone.

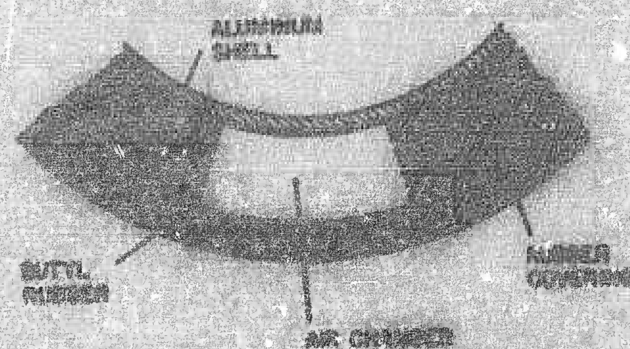

Figure 102. Section of 9A hydrophone.

7.6.23 Nondirectional Magnetostriction Transducer

Type: Magnetostriction.
Designer: Bell Telephone Laboratories.
Reference: NDRC Report No. 6.1-sr1097-1828, February 1, 1945.[224]
Use: To establish a uniform sound field in all directions.
Description: A magnetostriction transducer developed by BTL which transmits a 24-kc signal approximately uniform in all directions. This uses a ring oscillator of nickel, operating on its remanent flux, and vibrating in its fundamental radial mode.

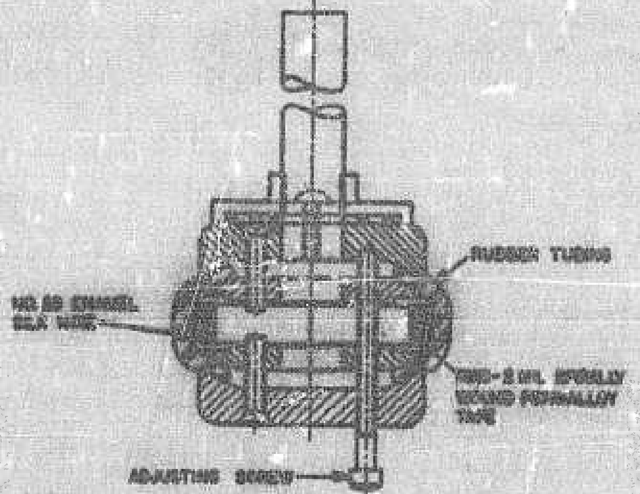

FIGURE 108. Nondirectional magnetostriction transducer.

7.4.32 10 kc, 20 kc, and 40 kc Transceiver Units

Type: 45° Y-Cut Rochelle Salt Crystal.
Designer: Bell Telephone Laboratories.
References: NDRC Report No. C4-sr20-592, December 10, 1942.[193]
NDRC Report No. 6.1-sr20-618, March 29, 1943.[194]
Use: For use in underwater sound transmission tests.

Description: A group of transceivers was constructed for the University of California, Division of War Research at San Diego having essentially the same directivity at their operating frequencies, namely 10, 20, and 40 kc.

Each unit consists of blocks of ¼ wavelength Y-cut Rochelle salt crystals. These crystal blocks are backed by lead resonators and immersed in castor oil. A sound-transparent rubber cover encloses the assembly. To reduce side lobes, the crystal blocks on the ends of the array have been given double the thickness of the others. In order that all units may have the same directivity, the linear dimensions of the crystal faces are reduced directly proportional to the wavelengths at which they operate, as shown in the following table.

Frequency	*Total crystal face*
10 c	1264 sq cm
20 c	371 sq cm
40 c	92.9 sq cm

The beams in the long axis have an angular width of about ±7½°, and in the short axis an angular width of about ±35°. The units were designed to operate with inputs up to 250 w. At their resonant frequencies, these units are only about 1 db below the ideal in efficiency.

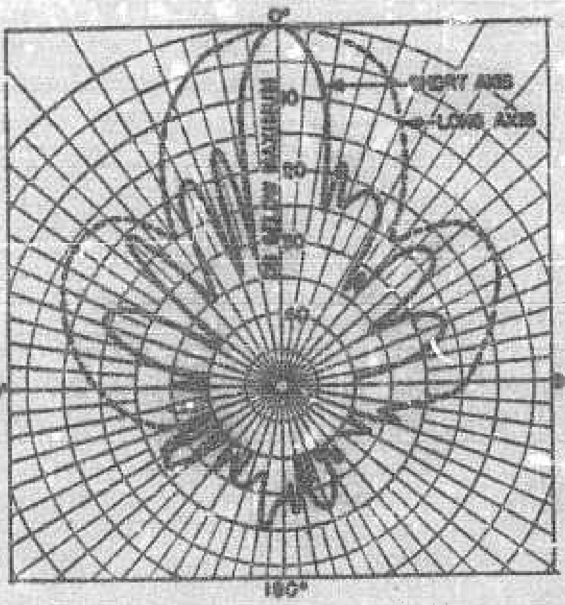

FIGURE 104. Directivity patterns, 10 kc transceiver unit No. 1 at 10.4 kc.

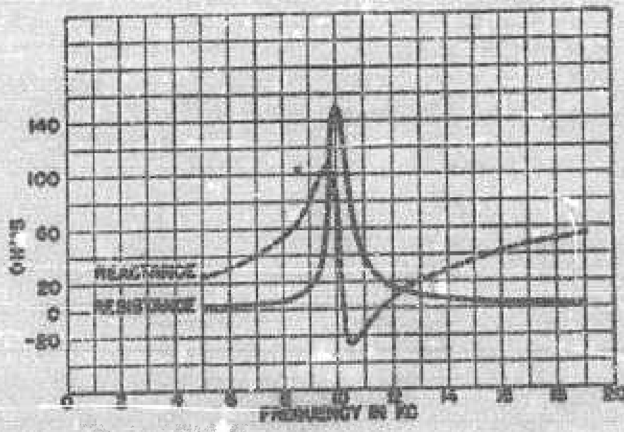

FIGURE 107. Impedance, 10 kc transceiver unit No. 1.

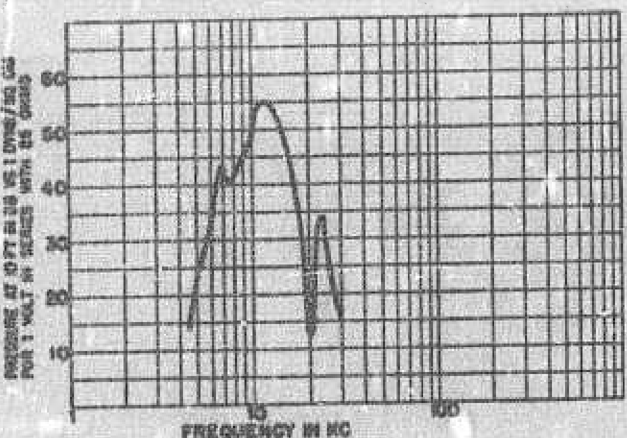

FIGURE 105. Transmitting response, 10 kc transceiver unit No. 1.

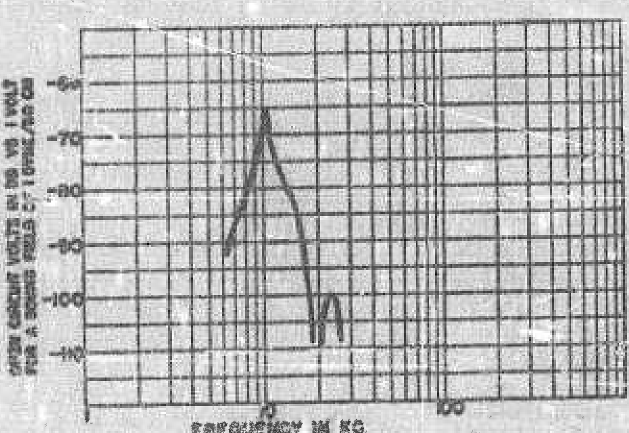

FIGURE 106. Receiving response, 10 kc transceiver unit No. 1.

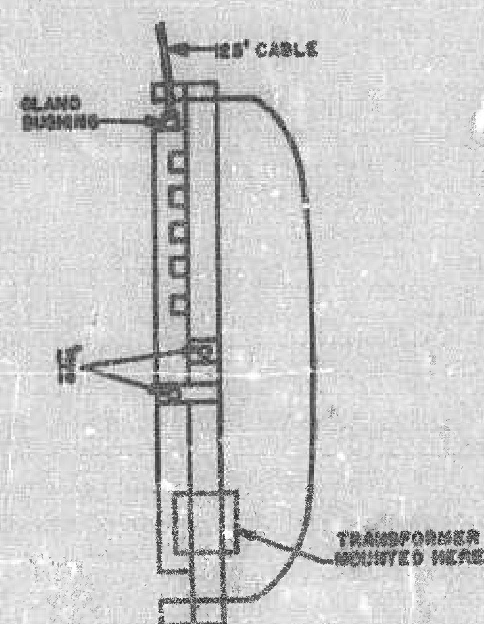

FIGURE 108. 10 kc transceiver unit No. 1.

7.4.24 S-124 Hydrophone

Type: Rochelle Salt Crystal—2-ft Line Hydrophone.

Designer and Manufacturer: Submarine Signal Company.

Reference: NDRC Report No. C4-sr20-144, July 13, 1942.[173]

Application: Underwater sound measurement in frequency range up to 40 kc.

Description: The S-124 hydrophone consists of a number of Rochelle salt crystal units in an aluminum housing 2 ft long with a 2 in. square cross section. Acoustic windows in the form of circular holes ⅞ in. in diameter are distributed over about 19 in. of the length of the hydrophone. Thirteen of these holes are in each of two opposite sides of the hydrophone. The capacity of the crystals including a 25-ft length of 2-conductor rubber-covered cord is 2,300 $\mu\mu f$.

Measured Impedance:

at 1 kc = 1490 — j21500 ohms
at 5 kc = 268 — j4430 ohms
at 20 kc = 121 — j904 ohms

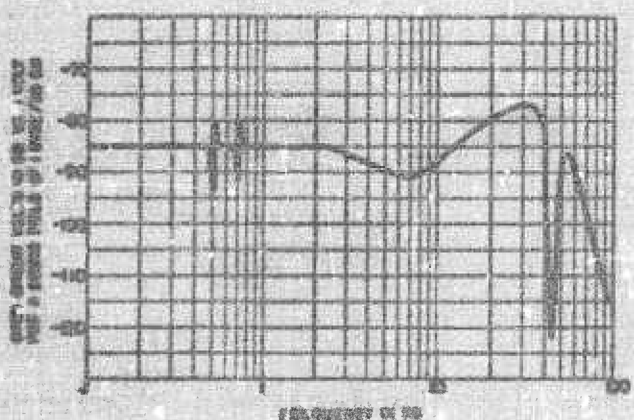

Figure 109. Receiving response, S-124 hydrophone.

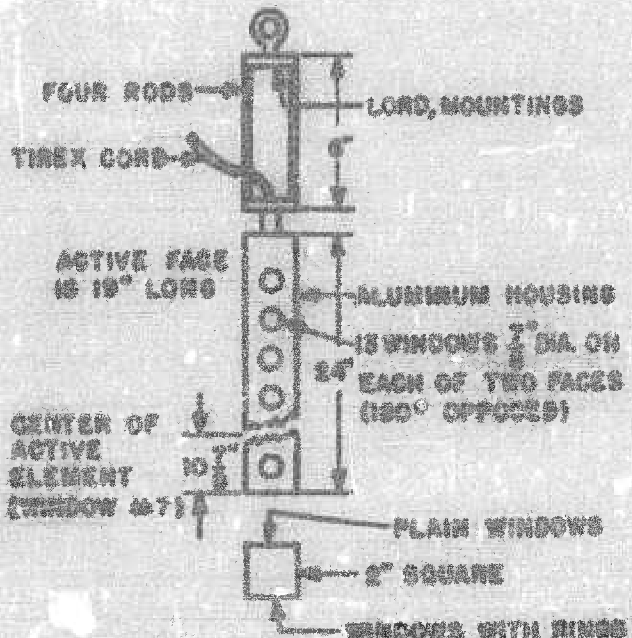

Figure 110. S-124 hydrophone.

7.6.25

SS-6 Hydrophone

Type: Rochelle Salt Crystal—6-ft. Line Hydrophone.
Designer and Manufacturer: Submarine Signal Company.
Reference: NDRC Report No. C4-sr20-144, July 13, 1942.[173]
Application: Underwater sound measurements in audio frequency range.
Description: The SS-6 hydrophone consists of a number of Rochelle salt crystal units in a steel housing approximately 6 ft long with a 2-in. square cross section. An acoustic window in the form of a slit ⅝ in. wide and about 63 in. long is in the side of the housing just over the crystal units. The capacity of the crystals, including a 30-ft length of coaxial cable, is 6,900 $\mu\mu$f.
Measured Impedance:

at 1 kc = 414 — j4600 ohms
at 5 kc = 165 — j825 ohms
at 10 kc = 69.7 — j617 ohms

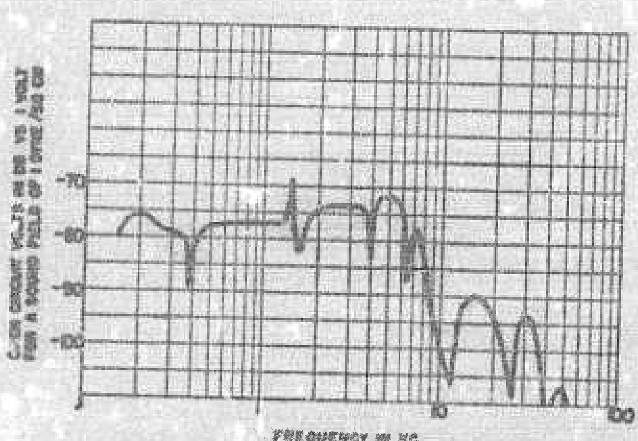

FIGURE 111. Receiving response, SS-6 hydrophone.

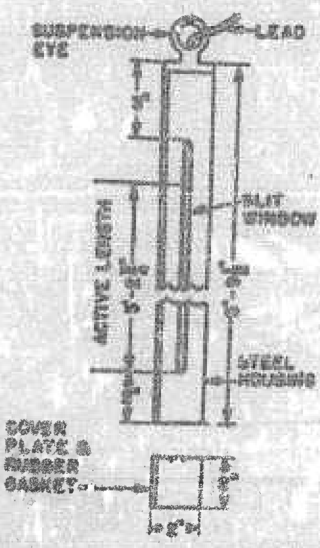

FIGURE 112. SS-6 hydrophone.

7.6.26 2A Condenser Hydrophone

Type: Electrostatic (condenser).

Designer and Manufacturer: Radio Corporation of America.

Reference: NDRC Report No. C4-sr20-291, October 27, 1942.[164]

Description: The 2A is a condenser transmitter type. The cylindrical housing has approximately a 17-in. overall length and 6-in. diameter. It contains a two-stage preamplifier which is designed to work into a load impedance of 500 ohms. A 6-conductor cable attached to the unit provides the supply voltages to the preamplifier and carries the output leads and calibrating leads.

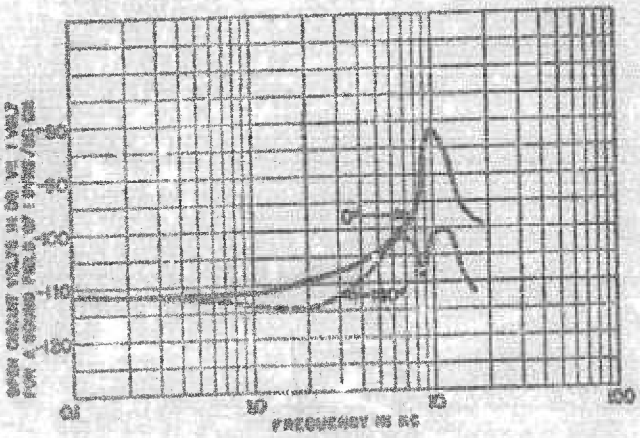

FIGURE 113. Receiving response, 2A condenser hydrophone.

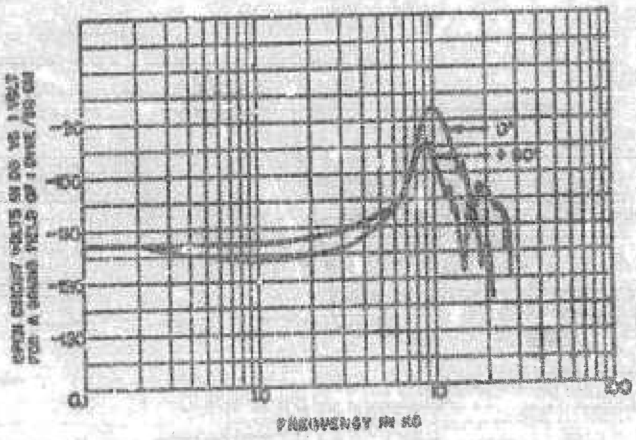

FIGURE 114. Receiving response, 2A condenser hydrophone, not including preamplifier.

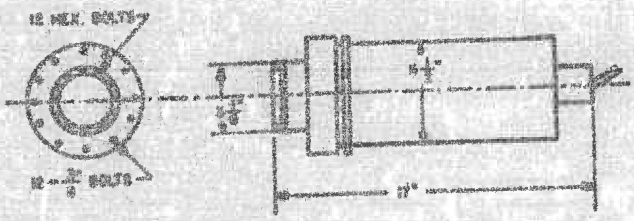

FIGURE 115. Drawing, 2A condenser hydrophone.

7.6.27

RCA Electrodynamic Hydrophone

Type: Electrodynamic.

Designer and Manufacturer: Radio Corporation of America.

References: USRL Orlando Project No. 17, March 4, 1944.
See also, "Calibrated Subaqueous Microphones," H. F. Olson and J. Preston, RCA Laboratories, October 26, 1943.[309]

Use: Standard for calibration measurements.

Description: This instrument is of simple construction. The diaphragm is a $\frac{1}{16}$-in. thick dome-shaped steel shell and it is coupled to a movable coil located in a magnetic field.

Threshold: —57 db vs 1 dyne per sq cm at 20 kc.

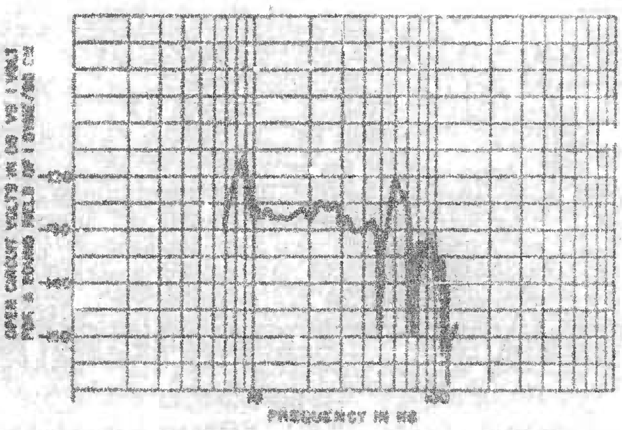

FIGURE 116. Receiving response, electrodynamic hydrophone.

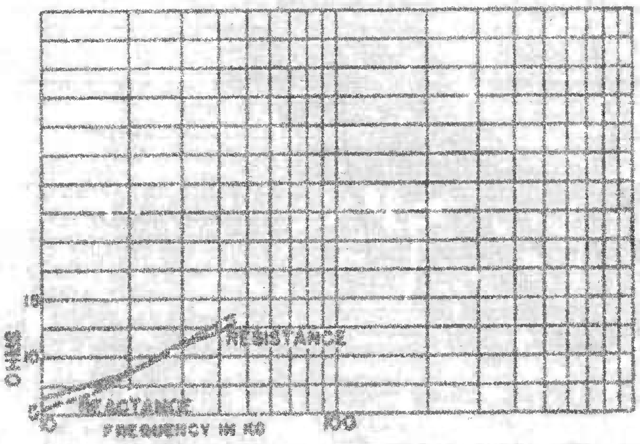

FIGURE 117. Impedance, electrodynamic hydrophone.

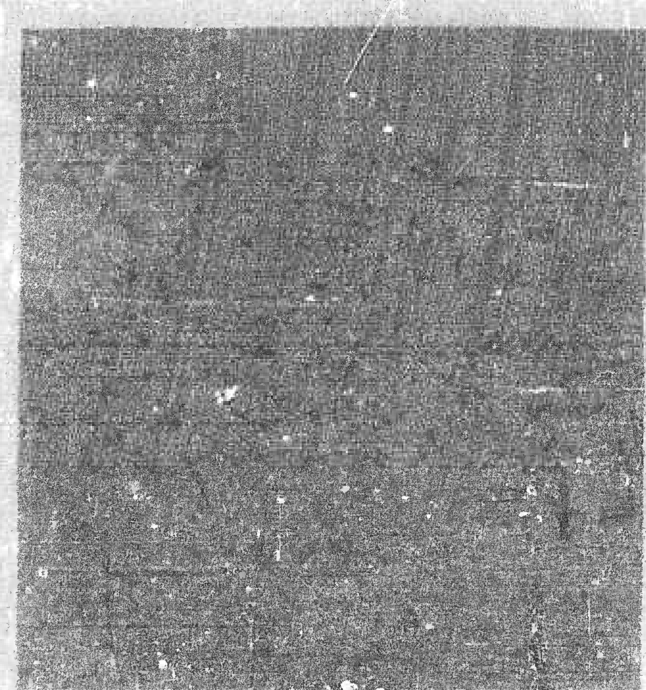

FIGURE 118. Electrodynamic hydrophone.

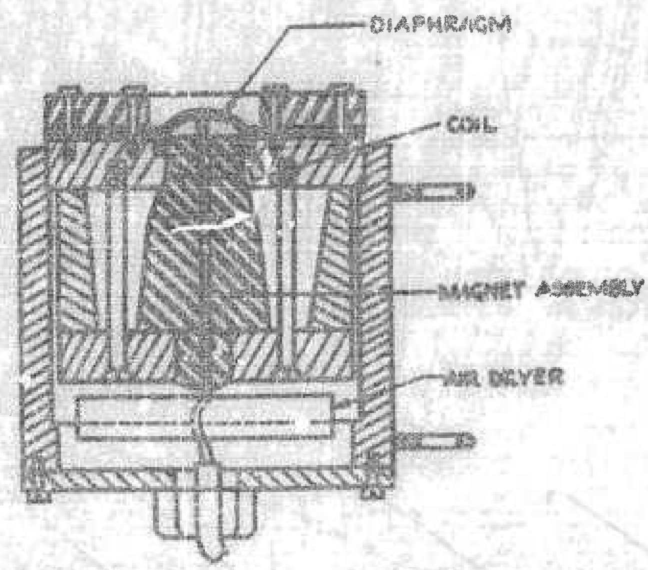

FIGURE 119. Cross section, electrodynamic hydrophone.

7.6.26

RCA Magnetostriction Hydrophone

Type: Magnetostriction (nickel).

Designer and Manufacturer: Radio Corporation of America.

References: USRL Orlando Project No. 117, March 4, 1944.

See also, "Calibrated Subaqueous Microphones," H. F. Olson and J. Preston, RCA Laboratories, October 28, 1943.[206]

Use: As standard in calibration measurements.

Description: The transducer element is a nickel tube ⅝ in. in diameter, 2 in. in length, and 0.015 in. in wall thickness. The polarizing flux is supplied by four small Alnico magnets. A coil of insulated wire is wound around the magnets.

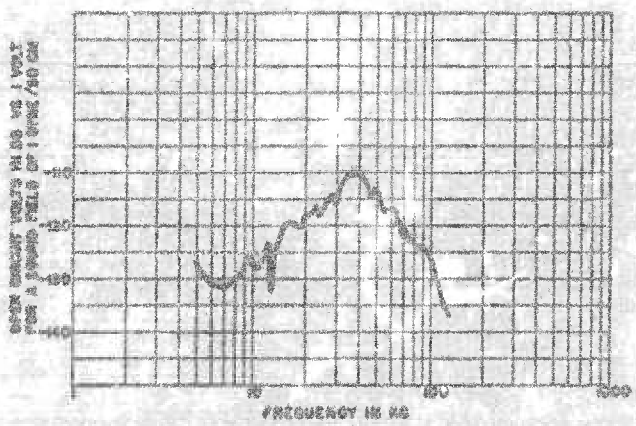

FIGURE 120. Receiving response, magnetostriction hydrophone.

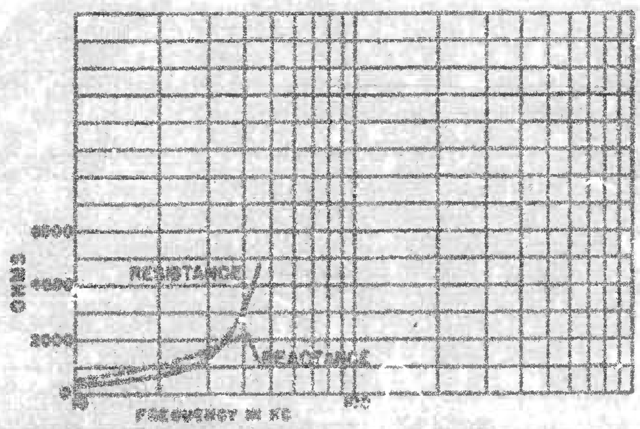

FIGURE 121. Impedance, magnetostriction hydrophone.

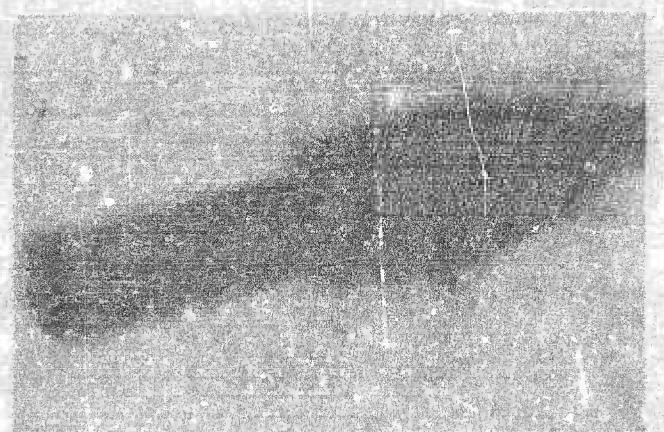

FIGURE 122. Magnetostriction hydrophone.

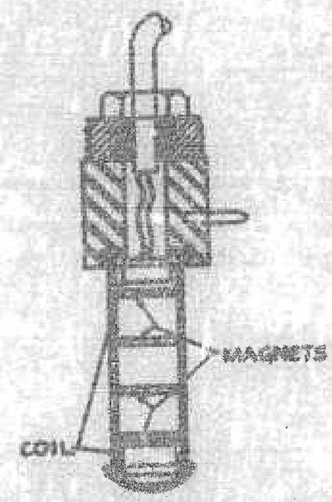

FIGURE 123. Cross section, magnetostriction hydrophone.

7.6.20 USDAR

Type: Quartz Crystal.

Designer and Manufacturer: Radio Corporation of America.

References: NDRC Report No. 6.1-sr1130-1632, June 30, 1944.[217]
NDRC Report No. 6.1-sr1130-1821, August 15, 1944.[218]
NDRC Report No. 6.1-sr1130-1822, August 18, 1944.[219]

Use: Small object location by echo ranging.

Description: The USDAR is a light, portable, hand-operated echo-ranging device which can be carried by one man and is used for locating small objects in the water, for example, in detecting mines during landing operations. It weighs about 5 lb and is cylindrical in shape and 10 in. long, as shown in Figure 132. A battery box weighing about 10 lb is connected to it by a 8-ft cable and must be carried with the unit.

The device contains as an active element a 1-in. diameter circular quartz disk with a thickness resonance at 500 kc. One face of the crystal is in contact with the water. The associated electronic circuit shown in Figure 133 is supplied with power by the dry cells in the battery box. The principle of operation is as follows: A signal of midfrequency 500 kc is frequency modulated sinusoidally at a rate of 12 c with a frequency swing of ±4,000 c. This signal is continuously transmitted as sound by the crystal, and when the sound strikes an object, an echo is returned to the crystal. Thus both transmitted and received signal voltages appear across the crystal simultaneously. The associated circuit then selects the difference frequency of the transmitted and received signals. This is amplified by the audio frequency amplifier and impressed on two HA-1 type Western Electric Company head receivers connected in series.

There is a frequency difference between the echo and outgoing signal due to the transit time of the echo to and from the reflecting object. Figure 129A shows the frequencies of the echo and outgoing signal as functions of time, and Figure 129B shows the audio difference frequency as a function of time. Twice during each 1/12 of a second the signal and echo have the same frequency, so the audio difference frequency becomes zero at these instants. Between these instants the difference frequency reaches a maximum, the magnitude of which depends on the acoustic path length. The maximum audio frequency difference f_{max} is given by (see Figure 130)

$$f_{max} = 2f_d \sin\left(\frac{f_m d}{2{,}500}\right),$$

where f_d = deviation frequency,
f_m = modulation frequency,
d = object distance (feet).

Thus the audio frequency increases with distance up to about 4,000 c at 100 ft and then decreases again.

The magnitude of the audio signal is roughly proportional to the product of the outgoing signal and the echo magnitudes. Since the former is fixed, the audio frequency signal depends on the intensity of the echo, that is, on the type of reflecting object and on its distance. Thus the audio signal decreases with distance. This is shown in Figure 131, where the

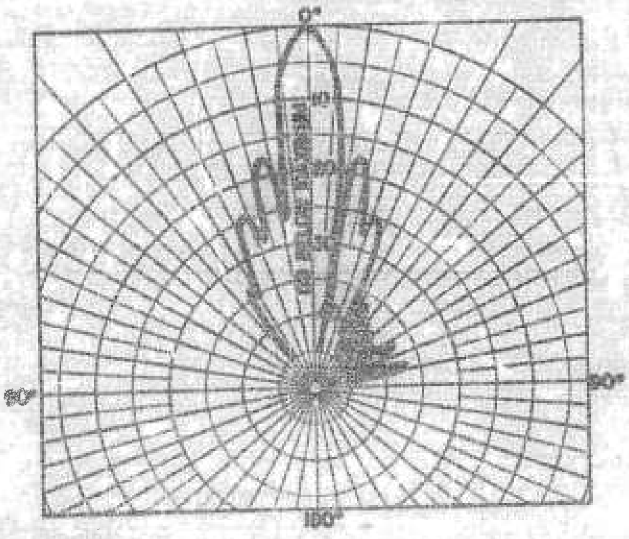

Figure 124. Directivity patterns, USDAR 500 at 496.6 kc.

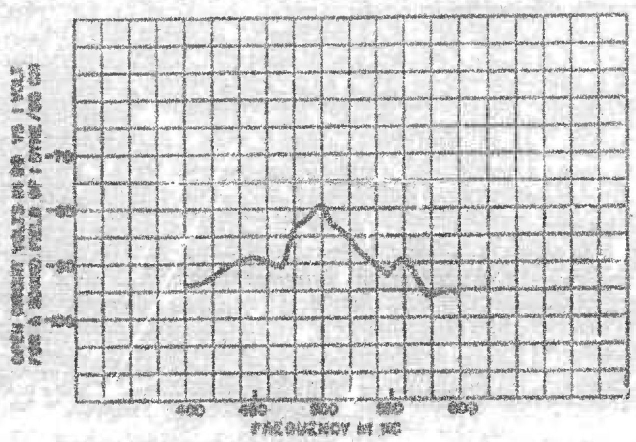

Figure 126. Receiving response, USDAR 500.

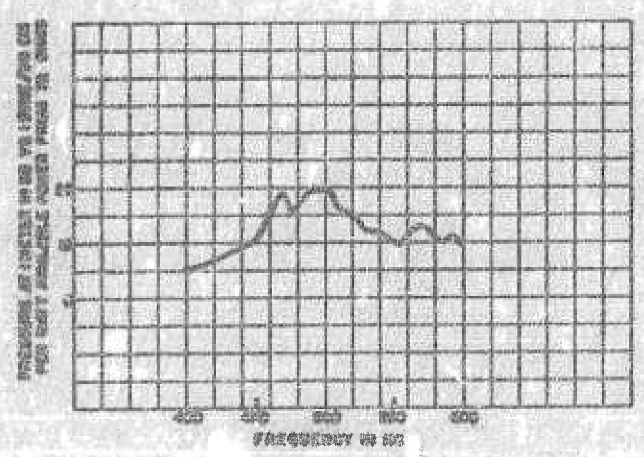

Figure 125. Transmitting response, USDAR 500.

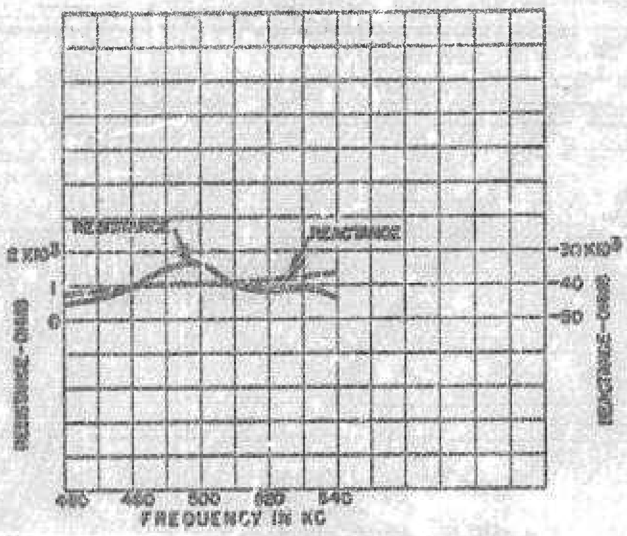

Figure 127. Impedance, USDAR 500.

audio frequency voltage across the headphones is plotted against object distance. On this figure the decrease of signal level with decreasing distance is due to overloading of the audio circuit.

From the above description it is seen that the object distance can be approximately estimated from the frequency and intensity of the audio signal, as well as from its bearing (determined from direction in which the device is aimed) and approximate knowledge of the slope of the bottom.

Experimental units operating at 250 kc and 1,000 kc were also tested. As shown in Table 1, the 1,000 unit was inferior to both the 250 and 500 units. The 250 unit performed as well as the 500, but ease in obtaining the smaller crystals used in the 500 led to the further development and improvement of the 500 unit. Modification in the gain characteristics of the audio frequency circuit resulted in the major part of the improvement of the 500 modified over the 500-1 unit.

TABLE 1. Calibration tests.

Unit	Diameter of crystal (in.)	Self-driven pressure at 10 ft distance (db vs 1 dyne per sq cm.)	Receiving response at peak (db vs 1 volt)	Audio response at 50 ft (db vs 1 volt in series with crystal)	Directivity index (db)	Calculated signal reflector at 50 ft (db vs 1 volt)
1000-2	½	81.4	−94.5	−3.9	−27.5	−52.2
500-1	1	80.3	−79.5	−7.0	−28.7	−35.2
250-1	2	81.6	−76.2	−0.45	−28.2	−38.0
500 modified	1	80.3	−79.5	−28.0	−28.7	−14.0

TABLE 2. Performance tests.

Unit	Maximum range (ft)	Noise voltage	Audio frequency voltage across head receivers—reflector at 50 ft (db vs 1 volt)
1000-2	70	0.02	−51.0
500-1	120	0.036	−36.2
250-1	130	0.035	−33.8
500 modified	130	0.1	−25.0

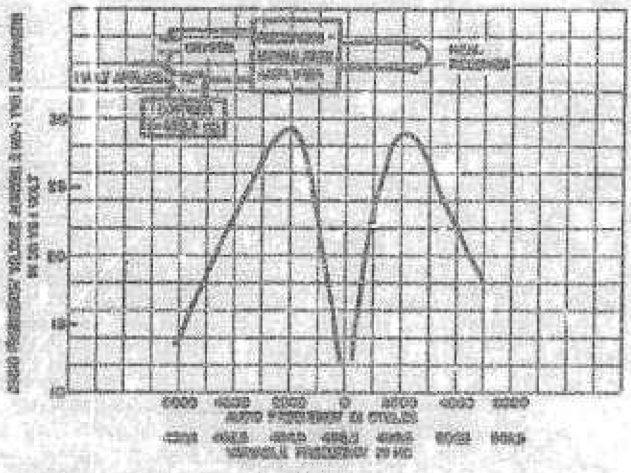

FIGURE 128. Gain frequency characteristics of audio circuit of USDAR 500.

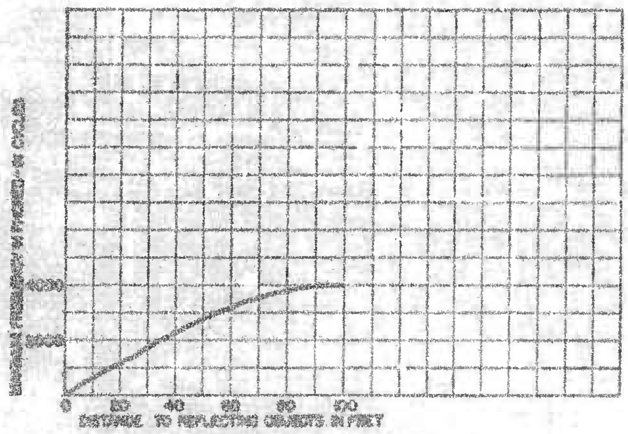

FIGURE 130. Maximum frequency heard in phones versus distance to reflecting object.

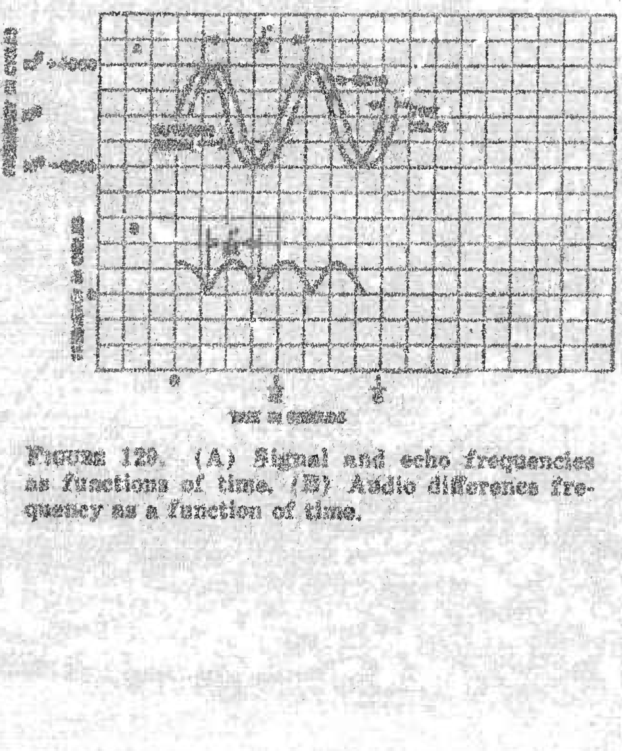

FIGURE 129. (A) Signal and echo frequencies as functions of time. (B) Audio difference frequency as a function of time.

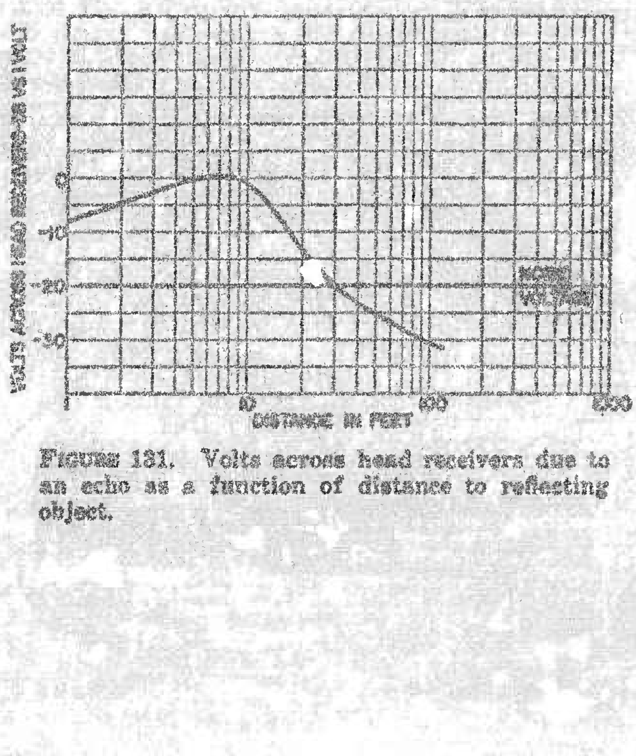

FIGURE 131. Volts across head receivers due to an echo as a function of distance to reflecting object.

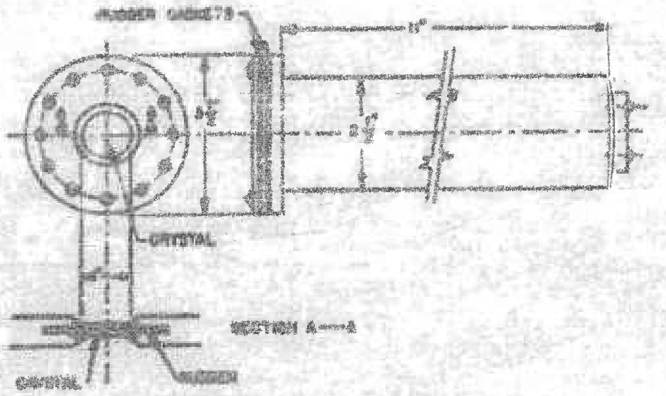

FIGURE 132. Drawing, USDAR 500.

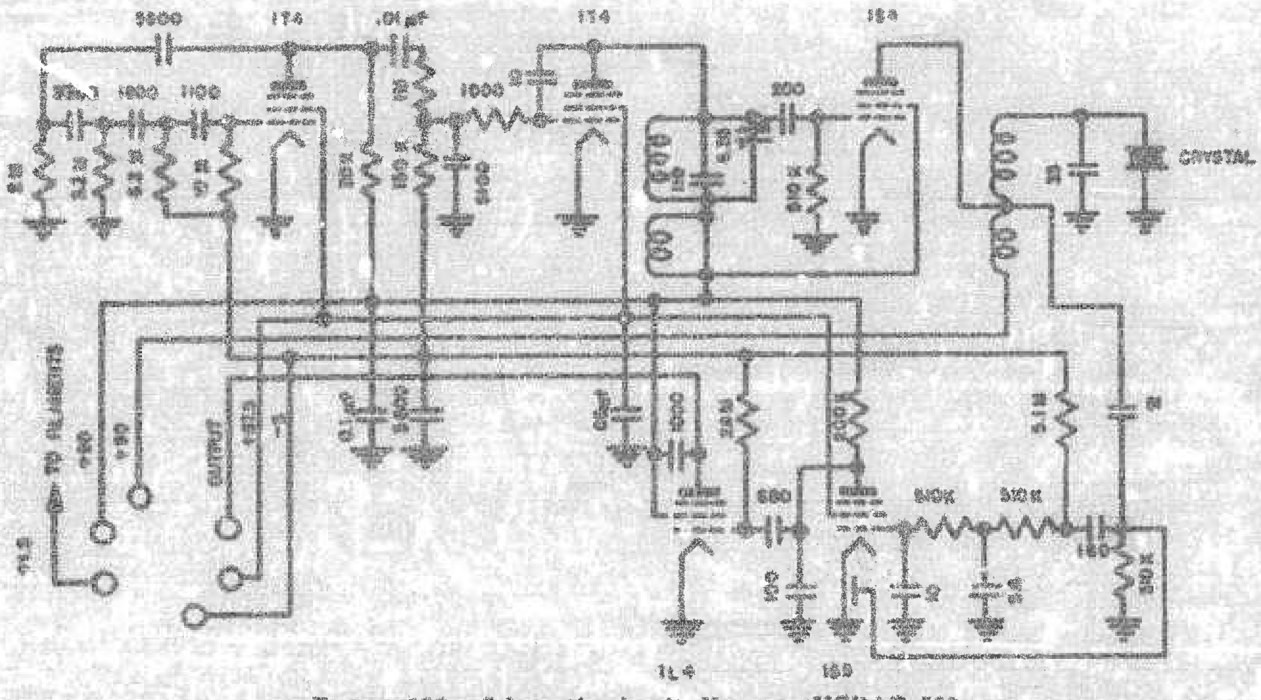

FIGURE 133. Schematic circuit diagram, USDAR 500.

7.6.39

General Electric Carbon Hydrophone

Type: Carbon.

Designer and Manufacturer: General Electric Company.

Reference: NDRC Report No. C4-sr20-293, November 12, 1942.[185]

Use: As sound element in a binaural listening system.

Description: A carbon button is mounted inside a soft rubber cap. The button is closed by a plu· .er which is rigidly attached to a brass cylinder. The supply circuit consists of 4½ v, dc, through a filter consisting of a series choke coil of 60 h inductance with 5.8 ohms d-c resistance and a ½-μf shunt condenser. The response of the hydrophone is not a linear function of incident sound pressure as shown on the receiving response curve.

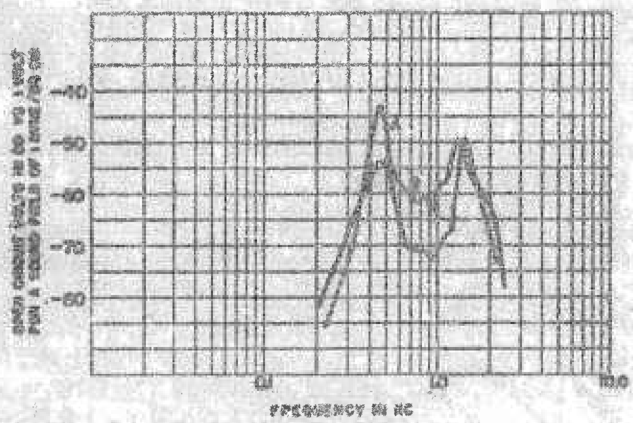

FIGURE 134. Receiving response, carbon hydrophone.

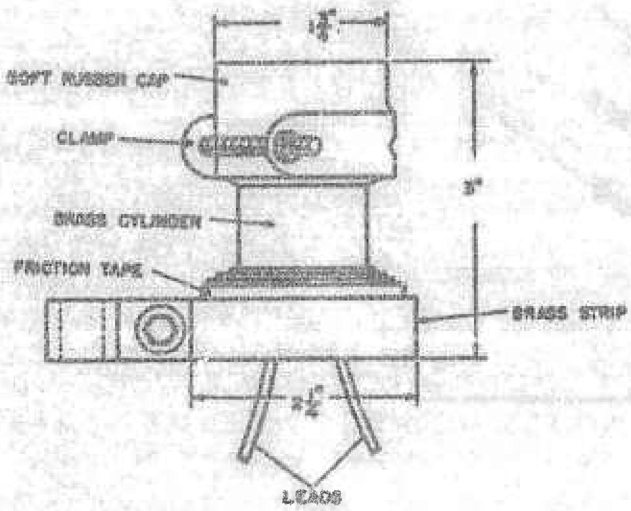

FIGURE 135. Carbon hydrophone.

7.8.21 Underwater Object Locator

Type: L-Cut Rochelle Salt Crystal.

Designer and Manufacturer: General Electric Company.

Reference: NDRC Report No. 6.1-sr1130-2302, July 23, 1945.[228]

Use: Small object location by echo ranging.

Description and Application: The Underwater Object Locator [UOL] developed by the General Electric Company is a scanning sonar system that reproduces on a cathode-ray tube screen the shape of the reflecting object. In essence, this system floods a given area with sound and then proceeds to scan the reflections and presents them in their proper order on the screen.

In practice, this system differs from the usual sonar systems in that the transmitter and receiver are each mounted in separate streamlined housings. The transmitter is located on the starboard side of the vessel and the receiver on the port side. The transmitter radiates a sound beam about 10° wide and 18° high at a frequency of either 750 kc or 250 kc. This beam is swept from left to right to cover a field of view of 120° in about 2 sec and may be pointed anywhere between horizontal and 70° downward. The choice of frequency is determined by the range and definition desired—750 kc being used for greater definition and shorter effective range. Either of these two frequencies may be chosen by simply rotating the combination of two projectors mounted back to back in the transmitter housing. One projector is designed for operation at 750 kc and the other at 250 kc. The active elements in both projectors are L-cut Rochelle salt crystals. Approximately 100 w of driving power is used with each projector.

The receiver unit is a highly directional device selective to signals within a circular beam approximately 1° across. Thus the receiver looks at a spot only 20 in. in diameter at 100 ft. This narrow beam is obtained by use of a parabolic reflector 14 in. in diameter.

Horizontal scanning is accomplished by mechanically rotating the receiver in synchronism with the transmitter; however, it is so arranged that the rotation of the receiver lags that of the transmitter in its sweep across the field of view. This lag allows time for the sound energy to travel out to the object and back again. The lag time or "range" is adjustable.

Vertical scanning is accomplished by scanning electrically a vertical row of crystals in the receiving unit placed along the focal curve of the parabolic reflector.

The receiving unit consists of two rows of small Rochelle salt crystals with 22 crystals in one row for operation at 750 kc and 15 crystals in the remaining row for operation at 250 kc. These crystals are X-cut Rochelle salt. Each of these crystals is connected to a capacity-type scanner which connects one crystal at a time to the following electrical system. This scanner rotates at a speed of about 3,600 rpm and is so constructed that it scans the elements three times in one revolution. This produces about 4,000 picture elements in 1 sec for 750 kc operation. The vertical field of view is about 15° for both frequencies.

Since in exploring small objects with highly directional beams any ex-

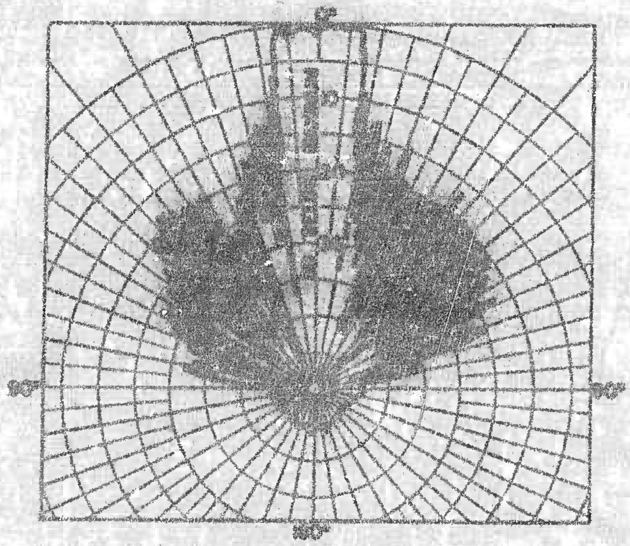

FIGURE 136. Directivity pattern, projector 730 No. 3 at 730 kc. Rotated around short axis.

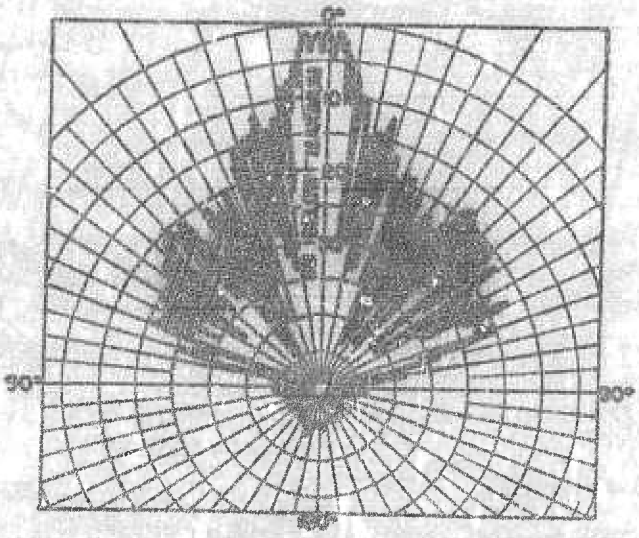

FIGURE 137. Directivity pattern, projector 730 No. 3. Rotated around long axis.

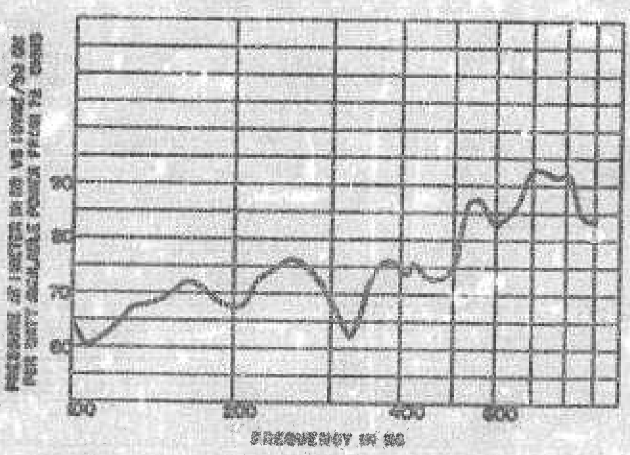

FIGURE 138. Transmitting response, projector 730 No. 3.

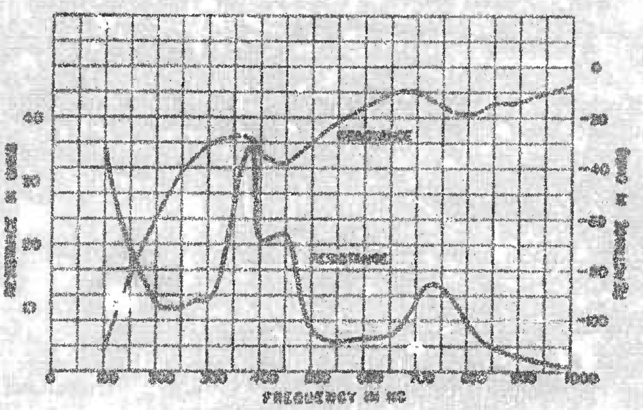

FIGURE 139. Impedance, projector 730 No. 3.

traneous motion can and will introduce distortion, the complete system has been stabilized for both pitch and roll.

In some of the latest installations, three frequencies of transmission have been used in order to minimize cross talk. For the short (high definition) range these are 710 kc, 730 kc, and 750 kc, while for the long range they are 210 kc, 230 kc, and 250 kc. For any given range the three frequencies are used successively in such a manner that the receiver is never tuned to the same frequency that is being transmitted at that instant. In addition to eliminating electric cross talk this technique also minimized extraneous acoustic signals due to reflection from close objects, such as the hull of the ship. The switching time is adjustable and may be tied in with the range control.

The range of this instrument is, of course, a function of the size and shape of the reflecting object. For large objects, e.g., a submarine, the maximum range at which fair definition is preserved is on the order o 600 ft. For smaller objects, such as mine cases, the maximum range is on the order of 180 ft.

Directivity index of projector 730 No. 3: At 730 kc = −25.5 db.

Acoustic Axis. Reference line adopted in transducer calibration, usually the direction of maximum response.

ADP. Ammonium dihydrogen phosphate crystal having marked piezoelectric properties.

Asdic. British echo-ranging equipment; letters are derived from "Anti-Submarine Development Investigation Committee."

Baffle. A shield used to modify an acoustic path.

BDI. Bearing deviation indicator.

BTL. Bell Telephone Laboratories.

Cavitation. The formation of vapor or gas cavities in water, caused by sharp reductions in local pressure.

Chemical Recorder. An indicator which records range on chemically treated paper.

Crest Factor. In this volume, $\sqrt{2}$ times the ratio of the peak-to-rms pressure of an acoustic wave.

Crystal Transducer. A transducer which utilizes piezoelectric crystals, usually Rochelle salt, ADP, quartz, or tourmaline.

CUDWR. Columbia University Division of War Research.

Cut-ons. Method of bearing determination from initial and final echoes obtained as the echo-ranging beam is swept across the target.

DDI. Depth deviation indicator.

Directivity Index. A measure of the directional properties of a transducer. It is the ratio, in db, of the average intensity, or response, over the whole sphere surrounding the projector, or hydrophone, to the intensity, or response, on the acoustic axis.

Dome. A transducer enclosure, usually streamlined, used with echo-ranging or listening devices to minimize turbulence and cavitation noises arising from the passage of the transducer through the water.

DTMB. David Taylor Model Basin.

Echo Repeater. Artificial target, used in sonar calibration and training, which returns a synthetic echo by receiving, amplifying, and retransmitting an incident ping.

ERSB. Expendable radio sono buoy.

Hydrophone. An underwater microphone.

Hydrophone, Velocity-Type. A pressure-gradient hydrophone.

JP, JT. Submarine sonic listening systems employing magnetostriction hydrophones.

Magnetostriction Effect. Phenomenon exhibited by certain metals, particularly nickel and its alloys, which change in length when magnetized, or (Villari effect) when magnetized and then mechanically distorted, undergo a corresponding change in magnetization.

MIT-USL. Massachusetts Institute of Technology Underwater Sound Laboratory.

NDRC. National Defense Research Committee.

NLL. New London Laboratory of CUDWR.

NOL. Naval Ordnance Laboratory.

NRL. Naval Research Laboratory.

N-Series (transducers). Navy designation for echo-sounding equipment.

OSRD. Office of Scientific Research and Development.

Piezoelectric Effect. Phenomenon, exhibited by certain crystals, in which mechanical compression produces a potential difference between opposite crystal faces, or an applied electric field produces corresponding changes in dimensions.

Ping. Acoustic pulse signal projected by echo-ranging transducer.

PPI. Plan position indicator.

Pressure-Gradient Transducer. Transducer, such as a moving-ribbon hydrophone, in which the moving element responds to pressure difference rather than to pressure.

Projector. An underwater acoustic transmitter.

QC. Standard Navy echo-ranging equipment using a magnetostriction transducer.

QH. Navy designation for CR scanning sonar (originally applied to HUSL designs) using magnetostriction transducers.

QL. Navy designation for FM sonar of UCDWR design.

Radio Sono Buoy. A buoy listening device that contains a hydrophone for receiving target signals and a radio transmitter for relaying the signals to patrolling air or surface craft.

Rear Response. The maximum pressure within ±60 degrees from the rear of the transducer in db relative to the pressure on the acoustic axis.

Recognition Differential. The number of db by which a signal must exceed the background in order to be recognized 50 per cent of the time.

ρc-Rubber. A rubber compound with the same ρc (density × velocity of sound) product as water.

Rochelle Salt. Potassium sodium tartrate ($KNaC_4H_4O_6 \cdot 4H_2O$) piezoelectric crystal used in sonar transducers.

Scanning Sonar. Echo-ranging system in which the ping is transmitted simultaneously throughout the entire angle to be searched, and a rapidly rotating narrow beam scans for the returning echoes.

Searchlight-Type Sonar. Echo-ranging system in which the same narrow beam pattern is used for transmission and reception.

Sonar. Generic term applied to methods or apparatus that use sound for navigation and ranging.

Sonic Frequencies. Range of audible frequencies, sometimes taken as from 0.02 kc to 15 kc.

SPTU. Split projector test unit.

Supersonic Frequencies. Range of frequencies higher than sonic. Sometimes referred to as ultrasonic to avoid confusion with growing use of the term supersonic to denote higher-than-sound velocities.

Target Strength. Measure of reflecting power of target. Ratio, in db, of the target echo to the echo from a 6-ft diameter perfectly reflecting sphere at the same range and depth.

Transducer. Any device for converting energy from one form to another (electrical, mechanical, or acoustical). In sonar, usually combines the functions of a hydrophone and a projector.

UCDWR. University of California Division of War Research.

USRL. Underwater Sound Reference Laboratories.

X-Cut. A cut in which the electrode faces of a piezoelectric crystal are perpendicular to an X or electrical axis.

Y-Cut. A cut in which the electrode faces of a piezoelectric crystal are perpendicular to a Y or mechanical axis.

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HUSL. Harvard Underwater Sound Laboratory.
MIT-USL. Massachusetts Institute of Technology Underwater Sound Laboratory.
NRL. Naval Research Laboratory.
RCA Laboratories. Radio Corporation of America.
UCDWR. University of California Division of War Research at the U. S. Navy Radio and Sound Laboratory.
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141. *Calibration of A24, A25 [illegible] A27 Toroidally-Wound Straight Magnetostr[illegible] Hydrophones*, Frank H. Graham an[illegible] Simmons, NDRC 6.1-sr1130-1193, USRL, [illegible] 17, 1943. Div. 6-554.2-M15
142. *Calibration of Magnetostriction Hydrophone COG 51055 #62*, L. Pauline Leighton, Erwin Shrader and Leslie L. Foldy, NDRC 6.1-sr1130-1363, USRL, Feb. 2, 1944. Div. 6-554.2-M17
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144. *Relative Pressure Measurement in Shock Waves from Small Underwater Explosives*, M. F. M. Osborne and A. H. Taylor, Report S-2305, NRL, June 10, 1944. Div. 6-551-M11
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229. *Calibration of Submarine Signal Company QCC Projector*, Eginhard Dietze, NDRC 6.1-sr1130-2306, USRL, Aug. 13, 1945. Div. 6-554.1-M7

Contract Numbers	*Name and Address of Contractor*	*Subject*
OEMsr-212	Western Electric Company (for Bell Telephone Laboratories, Inc.) 120 Broadway, New York, N. Y.	Studies and experimental investigations in connection with the development, construction and calibration of hydrophonic standard receivers and projectors and establish and operate field stations necessary for the maintenance of a calibration system.
OEMsr-20	The Trustees of Columbia University in the City of New York New York 27, New York	Studies and investigations and the development of methods and equipment pertaining to submarine warfare.
OEMsr-1130	The Trustees of Columbia University in the City of New York New York 27, New York	Studies and experimental investigations in connection with the testing and calibration of acoustic devices including operations of underwater sound reference test laboratories.
OEMsr-783	Western Electric Company (for Bell Telephone Laboratories, Inc.) 120 Broadway, New York, N. Y.	Studies and investigations in connection with the development of calibration devices and methods in the fields of hydrophonics, etc.
OEMsr-1189	Western Electric Company (for Bell Telephone Laboratories, Inc.) 120 Broadway, New York, N. Y.	Manufacture, stocking and repair of hydrophonic apparatus.

SERVICE PROJECT NUMBERS

The projects listed below were transmitted to the Executive Secretary, NDRC, from the Navy Department through the Office of Research and Inventions (formerly the Coordinator of Research and Development), Navy Department.

Service Project Number	[illegible]ubject
NS-139	Testi[illegible] [illegible]brating facilities.
NS-163	Pro[illegible] requ[illegible]rements and test limits.

HYDROPHONE ADVISORY COMMITTEE

The Hydrophone Advisory Committee was the name which soon came to be used for the Committee on Standards and Calibration appointed by the Coordinator of Research and Development, April 1942, for the following purpose: to assist in establishing calibration techniques, reference levels, and standard definitions and terms to be used generally by all groups making underwater sound measurements of interest to the Navy.

Shortly after the organization of this committee, Dr. Robert S. Shankland was selected to be its chairman. While from time to time the personnel of the committee changed, in general the following organizations were represented at meetings and were otherwise active:

Office of the Coordinator of Research and Development (now Office of Research and Inventions)
Bureau of Ships (940)
Naval Ordnance Laboratory
Naval Research Laboratory
Division 6:

> Columbia University Division of War Research at the U. S. Navy Underwater Sound Laboratory, Harvard Underwater Sound Laboratory, Massachusetts Institute of Technology Underwater Sound Laboratory, University of California Division of War Research at the U. S. Navy Radio and Sound Laboratory, Underwater Sound Reference Laboratories of Columbia University Division of War Research.

Bell Telephone Laboratories, Inc.
Brush Development Company
Radio Corporation of America
Submarine Signal Company

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